CLIMATE VARIABILITY, DROUGHT, AND DROUGHT MANAGEMENT IN TUNISIA'S AGRICULTURAL SECTOR

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ACRONYMS AND ABBREVIATIONS

Exchange Rate

1 US$ = 2.50 TD = 0.85 EURO

1 TD = 0.40 US$ = 0.352 EURO

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
APIA	Agricultural Investment Promotion Agency
BNA	Banque Nationale Agricole (National Agricultural Bank)
AR5	Assessment Report 5 (IPCC)
CDAS	Climate Data Assimilation System
CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CHJ	Jucar Hydrographic Confederation (Spain)
CLIVAR	Climate variability and predictability
CMIP3	Coupled Model Intercomparison Project 3
CMIP5	Coupled Model Intercomparison Project 5
CONAGUA	National Water Commission (Mexico)
CORDEX	Coordinated Regional Climate Downscaling Experiment
COSEM	Seed Cooperative
CRDA	Regional Offices of Agricultural Development
CRU	Climatic Research Unit
CTMA	Caisse Tunisienne d'Assurances Mutuelles Agricoles (Tunisian Fund for Mutual Agricultural Insurance)
CTV	District Offices of Agricultural Development
DGRE	General Directorate of Water Resources (MoAWRF)
DMI	Danish Meteorology Institute
DSS	Decision support system
ECMWF	European Center for Medium-Range Weather Forecasts
ENSO	El Niño Southern oscillation
E-OBS	Data set for precipitation, temperature, and sea level pressure in Europe
EU	European Union
FAO	United Nations Food and Agriculture Organization

FAOSTAT	Food and Agriculture Organization Statistics
FAS	Foreign Agricultural Service, USDA
FMD	Farm Management Deposit (Australia)
GDA	Groupements de Developpement Agricole (Agricultural development groups—cooperative societies for farmers within the PPI)
GDP	Gross domestic product
GHG	Greenhouse gas
GISS	Goddard Institute for Space Studies (NASA)
GISTEMP	Goddard Institute for Space Studies Surface Temperature Analysis
GNI	Gross national income
GMST	Global mean surface air temperature
GWP	Global Water Partnership
HadCRUT4	Hadley Centre/Climatic Research Unit gridded surface temperature data set 4
HMNDP	High-level Meeting on National Drought Policy
ICBA	International Center for Biosaline Agriculture
IDM	Integrated drought management
IDMP	Integrated drought management program
IDMS	Integrated drought management strategy
IMTA	Mexican Institute of Water Technology
INGC	National Institute for Field Crops, Ministry of Agriculture
INM	National Meteorology Institute
IPCC	Intergovernmental Panel on Climate Change
MENA	Middle East and North Africa
MARH	Ministry of Agriculture and Water Resources (now MoAWRF)
MO	Mediterranean oscillation
MoAWRF	Ministry of Agriculture, Water Resources, and Fisheries
MOI	Mediterranean Oscillation index
MT	Metric Ton
NAO	North Atlantic oscillation
NAOI	North Atlantic Oscillation index
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NDMC	National Drought Mitigation Center (UNL)
NDP	National drought policy
NDS	National drought strategy
NDVI	Normalized difference vegetation index
NGO	Nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
OEP	Office of Livestock and Pastures
ONAGRI	National Agricultural Observatory
ONI	Oceanic Niño Index
OSS	Sahara and Sahel Observatory
PPI	Public irrigation perimeters

PPIC	Public Policy Institute of California
PRONACOSE	National Program against the Drought (Mexico)
RCP	Representative concentration pathway (of greenhouse gas emissions)
RDMS	Regional drought management system
RFCS	Rural Financial Counselling Service (Australia)
RPCA	Rotated principal component analysis
RVCA	Rapid value chain assessment
SINEAU	Unified National Water Resources Information System
SMAS	Maghreb drought early warning system
SODMI	Standardized Operative Drought Monitoring Indicators
SONEDE	Société Nationale d'Exploitation et de Distribution des Eaux
SPI	Standardized precipitation index
SRES	IPCC Special Report on Emission Scenarios
UKMO	United Kingdom Meteorological Organization
UN	United Nations
UNC	University of North Carolina
UNCCD	United Nations Convention to Combat Desertification
UNDESA	United Nations Department of Economic and Social Affairs
UNL	University of Nebraska Lincoln
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDM	United Stares Drought Monitor
UTAP	Tunisian Farmers Union
WDR	World Development Report
WeMO	Western Mediterranean oscillation
WMO	World Meteorological Organization

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ABSTRACT

Climate change and recurrent climate events are making water-scarce countries like Tunisia and its agricultural lands drier and more vulnerable to drought. These recurrent climate events are also known as teleconnections and include natural climatic events such as the El Niño Southern oscillation (ENSO), the North Atlantic oscillation (NAO), and the Mediterranean oscillation (MO). These climate phenomena contribute to droughts, which negatively affect key rain-fed crops, such as wheat and barley, and livestock. As a result, farmers are becoming more vulnerable as climate change and teleconnections make temperatures rise and rainfall become more sporadic.

Agriculture is important for rural communities and the overall Tunisian economy. Twenty percent of the population is employed in agriculture, which accounts for 10 percent of the country's gross domestic product (GDP) and 10 to 12 percent of total exports, on average. Wheat and other rain-fed crops are critical to food security and livestock survival and are the crops most affected by climate variability. Climate change's adverse impacts on agriculture are a contingent liability for the Tunisian economy, including for the country's GDP, trade balance, and balance of payments. As agricultural and agro-industrial outputs fall, food and fodder imports must rise to meet domestic demand. Therefore, this report suggests additional action on implementing integrated drought management (IDM) on top of what the government is already doing.

Food and agriculture value chains are affected by climate events. This report includes detailed analyses of two key value chains, namely wheat and dairy. The analyses were done in representative lagging regions, including Jendouba for the dairy value chain and Siliana and Beja for the wheat value chain. Currently, wheat and dairy are the main subsectors in the lagging regions, and in the short term, strengthening these subsectors will increase jobs, incomes, and food security.

Multiyear drought and general rainfall variability are major challenges for Tunisian agriculture. Surface water is becoming scarcer, leading farmers to use groundwater to supplement crop and fruit tree irrigation. This form of adapting to water scarcity makes water even scarcer over time. To break this downward spiral requires improved water resource management and better enforcement of existing laws and regulations. International experience reveals this is an effective way to address both short-term and long-term water scarcity problems.

This study finds that the El Niño Southern oscillation (ENSO) was a less important contributor to the 2015–16 drought in Tunisia than other teleconnections. ENSO drought impacts are more pronounced in other parts of the world than in the Middle East and North Africa (MENA) region. This

report also examines wheat and dairy agriculture to determine how well they are adapting to climate change and climate variability. Current adaptation pathways to increase agricultural incomes and productivity focus on increasing tree crops, which generally are more resilient to drought than field crops. Still, improving water management is also an essential part of this adaptation plan.

With improved collaboration among public sector institutions and better access to information, farmers will make more effective investments. As a result, agribusinesses can become more profitable, which will contribute to higher incomes and greater employment. The Tunisian government could revise its current integrated drought management strategy (IDMS) into a more formal integrated drought management policy. This was recommended by the United Nations (UN) Food and Agricultural Organization (FAO), the World Meteorological Organization (WMO), and other international organizations and undertaken by numerous countries such as Mexico and Australia. Taking these actions will help Tunisia reduce the contingent liability from drought and achieve greater and more sustainable results for farmers and the national economy.

In summary, this report examines the impacts of more droughts and increasing climate variability on Tunisia's agricultural and livestock sector. The report focuses on the role of various atmospheric teleconnections, including the 2015–16 ENSO. The report also looks at scientific evidence on temperature and precipitation changes and how this will affect the occurrence and severity of drought in various parts of Tunisia. Within the agricultural sector, the report explores climate-related impacts on two key value chains: wheat and dairy products. It also examines the Tunisian government's evolution on drought management, including how it responded to the most recent drought. In addition, the report identifies gaps and persistent challenges in the country's drought management activities. Finally, the report proposes policy options to help Tunisia better protect its agricultural sector from drought and climate variability.

OVERVIEW

0.1 CLIMATE CHANGE, CLIMATE VARIABILITY, AND DROUGHTS IN TUNISIA

Warming of the climate is now "unequivocal," according to the Intergovernmental Panel on Climate Change (IPCC). Despite a "hiatus" in the early 2000s, global temperatures have risen again since 2012, with 2016 and 2017 being Earth's hottest and second hottest years on record (NASA News). Similar trends were recorded for the entire Middle East and North Africa (MENA) region and Tunisia, specifically. At the individual country level, there may be normal year-to-year variations from the global mean.

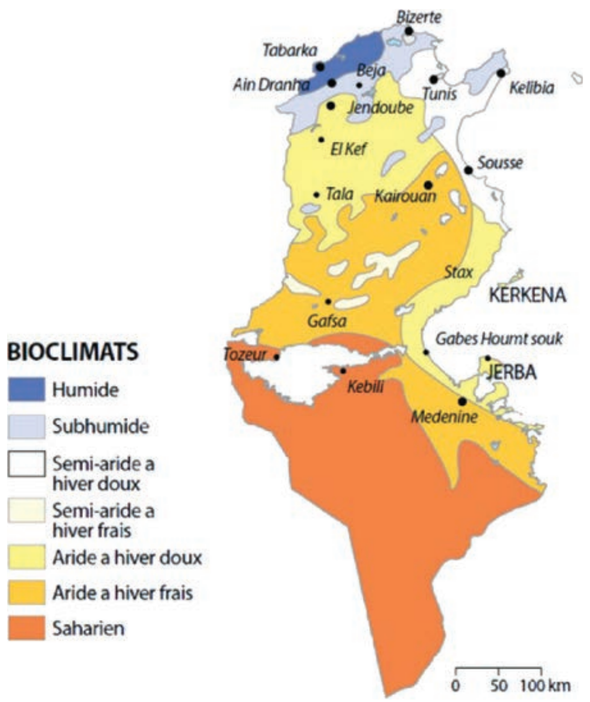
IPCC projections indicate a high likelihood of continued warming in Tunisia, where a 0.50°C per decade increase since the 1970s greatly exceeds the global average of 0.15°C. Under a business-as-usual scenario, 3°C to 7°C increases are projected by the end of the 21st century, with the largest increases (4°C to 7°C) occurring during summer months (June, July, and August). Under the same scenario, precipitation is projected to decline 10 to 40 percent annually, including 10 to 30 percent in the wet season, from October to April, and 10 to 40 percent in the dry season, from May to September.

More frequent and intense droughts are also associated with rising global temperatures and greater rainfall variability. Recent experience in MENA is consistent with this tendency. For the near term (2016–35), the general trend is toward higher exposure to drought. The likelihood of an increase in other extreme weather-related events, including flash floods, wildfires, and related hazards, is also significant. These global and regional trends provide the general scientific context for the present study, which explores the relationship between various climate phenomena. This includes the strong ENSO in 2015–16 and other teleconnections and recent increases in serious drought conditions in Tunisia.

0.2 THE CLIMATE OF TUNISIA

Tunisia's climate, including both rainfall and temperatures, varies considerably from north to south. It is strongly influenced by the Mediterranean Sea to the north and east and by the Sahara Desert to the south and southwest. Like the western Mediterranean as a whole, most of the rainfall occurs between October and May. This is because extratropical weather systems from Europe and the Atlantic Ocean bring colder air and cloudiness. This also reduces the rainfall gradient from north to

FIGURE 0.1 Tunisia's Bioclimatic Zones



Source: You et al. 2016.

south. Temperatures in the arid and semiarid southern and southwestern parts of the country are generally high, whereas rainfall is significantly higher from November to April in areas further to the north. Tunisia's major bioclimatic zones are depicted in Figure 0.1 Tunisia's Bioclimatic Zones .

In the northern and central parts of the country where agricultural activity predominates, the climate is characterized by hot dry summers and cool moist winters. These seasonal variations determine the growing period. Rainfall is irregular and varies considerably from the relatively humid coastal area to the desertlike conditions in the south. The past decade has seen a variety of noteworthy climate events in Tunisia, including numerous droughts, heat waves, and the occasional heavy rainfall and flooding.

0.3 THE ROLE OF TELECONNECTIONS

This study examines the impact from several teleconnections on a recent drought event in Tunisia. This includes a correlation analysis with standardized precipitation index (SPI) data. Teleconnections are climate anomalies—or oscillations—related to each other at large distances. This analysis was not limited to the 2015–16 ENSO event but also included the Mediterranean oscillation (MO).

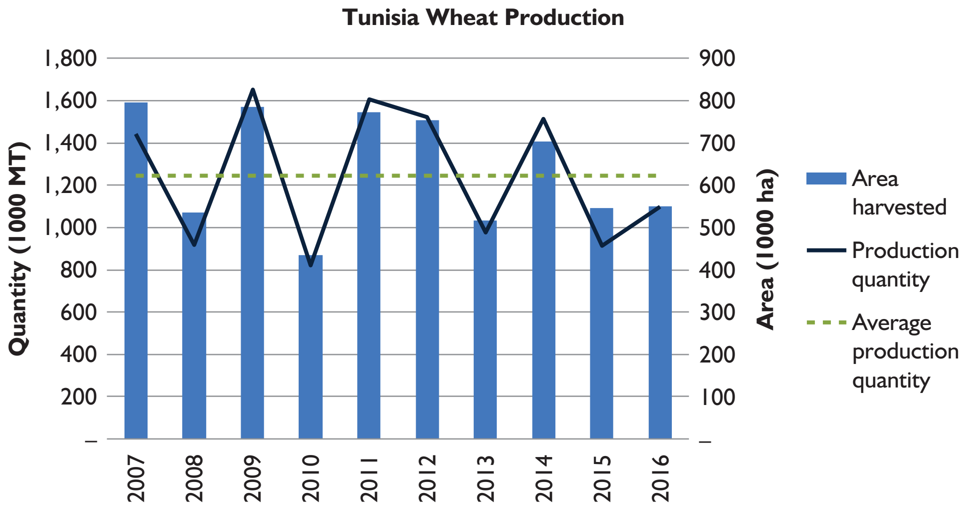
Despite ENSO's global significance, its influence on drought in Tunisia cannot be confirmed. However, other teleconnections, particularly the MO, appear to play a dominant role in the droughts occurring over the past two years in Tunisia and elsewhere in northern Africa. More detailed research is required on how local topographical conditions affect teleconnections and how ENSO and other climate oscillations affect local drought events in the region.

0.4 DROUGHT IMPACTS ON THE AGRICULTURAL SECTOR

Agricultural development remains largely dependent on rain. Agricultural water management is at the core of food security policies in Tunisia, where average rainfall is highly variable and averages only about 220 mm per year.[1] Renewable water resource availability amounts to 420 m^3 per year per inhabitant, which is below the absolute water scarcity threshold. Agriculture uses 80 percent of these resources. Climate change is predicted to increase temperatures, reduce precipitation, and increase weather variability. The government of Tunisia—through its Ministry of Agriculture—has invested

[1] The average annual water resource available is estimated at 36 billion cubic meters, but varies from 11 billion in dry years to 90 billion in wet years.

FIGURE 0.2 Tunisia Wheat Production, 2007–16



Source: Global Development Solutions 2017b analysis of Production, Supply and Distribution (PSD) Data Sets: Grains, United States Department of Agriculture (USDA) Foreign Agricultural Service (FAS), January 12, 2017, https://apps.fas.usda.gov/psdonline/downloads/archives/2017/01/psd_grains_pulses_csv.zip.

significantly in the mobilization, conservation, and management of surface water resources (see Box 0.1). However, with climate variability and climate change leading to more severe droughts, surface water may not meet farmers' irrigation needs, so they increasingly will rely on groundwater. This will intensify pressure on already-stressed aquifers.[2]

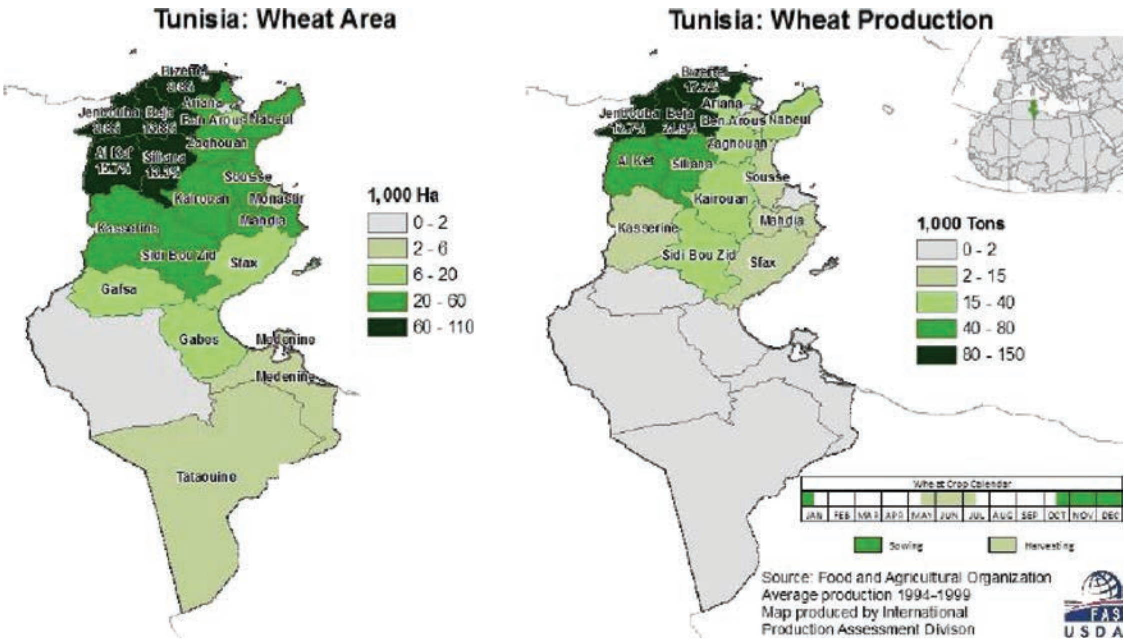
Droughts are a recurrent phenomenon in Tunisia and seem to be becoming more frequent. As a result, they are having increasingly serious local and national social and economic impacts. Since 1990, drought has been officially declared in 1994, 1995, 1997, 2000, 2001, 2002, 2008, 2010, 2013, and 2016. The most severe drought in 50 years took place for three consecutive years from 2000 to 2002. Formal government interventions on this drought cost an estimated US$54 million. Cereal production (for instance, wheat and barley), which is critical for both domestic livestock feed and food security, was adversely affected. This led to increased imports and a decline in overall economic growth.

Wheat is a leading crop for Tunisian agriculture and with olives and tomatoes ranks among the top three crops produced annually. In 2014, wheat ranked first for quantity produced (18 percent of the total national crop production) and second for harvested area (20 percent of the total national crop area, behind olives) (FAOSTAT). However, the country's wheat production varies significantly from year to year, mainly because of weather-related variability. During the 2007–16 period, Tunisia produced, on average, 1.2 million metric tons (MTs) of wheat annually on a harvested area ranging from 434,400 hectares (ha) to 961,500 ha (with an average of 639,000 ha), peaking in 2009 (Figure 0.2). Wheat production quantity fell 28 percent from 2007 to 2016 and remains in lockstep with harvested area, as the yield rate is relatively unchanged (2.0 MT/ha in 2016).

Tunisia's wheat production is predominately in the north and center regions of the country, where cultivation conditions, including rainfall, are more favorable (Figure 0.3). Even in the north

[2] Of the 273 aquifers identified in Tunisia, 71 are considered overexploited, with water use exceeding the renewal capacity of the aquifers by nearly 50 percent. Most aquifers in Tunisia's coastal areas face salinization problems.

FIGURE 0.3 Wheat Production Area and Quantity by Governorate



Source: United States Department of Agriculture (USDA) Foreign Agricultural Service (FAS), June 20, 2011.

region, where rainfall is more consistent, cultivation conditions vary. In the middle of the country, Beja governorate is significantly more productive than Siliana governorate in terms of yield rate. Together with dairy, wheat is the main subsector in the lagging regions, and in the short term, strengthening these subsectors can increase jobs, incomes, and food security.

The most recent drought, which began in November 2015 and extended through the spring of 2016, caused a drop in economic growth. This was caused by decreased agricultural output, mainly cereal production, and the cost of needed mitigation actions. This study assesses two agricultural value chains: wheat and dairy products. These two value chains suffered sharp production declines from climate and drought-related impacts in 2015–16.

0.5 IMPACTS ON THE WHEAT SUBSECTOR

Increasing water scarcity is the most pressing climate change impact on the wheat subsector. Some growers utilize government programs to partially recoup their investments in irrigation equipment. However, electricity costs for operating pumps or water charges from irrigation canals or other public utilities can be prohibitive.

Most wheat farmers (84 percent) surveyed for this study attribute declining yields to the lack of rain. A fifth of the wheat farmers indicate that a lack of irrigation water was also a factor, and another fifth attribute declining yields to increasing salinity of irrigation water. Milk producers, in turn, indicate that cows undergo heat stress for four to five months of the year (mid-May to mid-September). When

[3] https://www.pecad.fas.usda.gov/rssiws/al/crop_production_maps/nafrica/Tunisia_Production_wheat_Web.jpg

BOX 0.1 Development of Irrigation in Tunisia

Major infrastructure investments have allowed Tunisia to capture most of its scarce water, mobilizing 92 percent of renewable resources, and deliver it where it is most needed.[4] However, the Tunisian government has recognized the need to evolve from a supply side response (increasing water mobilization) to a demand management approach (improving overall efficiency and favoring the most productive uses of water). The government's 2030 water strategy includes the following main lines of action: (i) further increase storage capacity to harvest surface water, including the replacement of some existing dams; (ii) increase water transfer capacity and safety; (iii) renew old boreholes; (iv) restrict irrigation development in the north and halt it in the center and south; and (v) develop alternative, nonconventional resources, including treated wastewater reuse and brackish and sea water desalination. Measures to improve groundwater recharge are also considered. Overall, the volumes of water abstracted from groundwater resources could be reduced and replaced by nonconventional resources; the volumes mobilized from surface water would slightly increase and transfer to coastal regions. However, there is a limited scope for increased water allocation for irrigation usage.

Tunisia has developed its irrigation systems along modern standards. Investments in irrigation infrastructure have reached 35 percent of all agricultural investments in the past decades. This equipped 410,000 ha for irrigation, which is 95 percent of the estimated potential. Two-thirds of Tunisia's irrigated area has drip or sprinkler technology for on-farm irrigation.[5] In addition, the country has a long-standing program of innovative practices, such as artificial aquifer recharge and reuse of treated wastewater, even if on limited surfaces.[6] Tunisia's irrigated areas are concentrated in the north (48 percent), followed by the center (36 percent), and the south (16 percent). About 53 percent of the equipped area is on public irrigation schemes, whereas the remaining 47 percent is on private schemes.

Source: World Bank 2017.

this occurs, the quantity and quality of milk fall, as do the availability of forage and feed, and spoilage rates increase such that collectors reject milk more frequently.

Farmers have implemented a variety of adaptive management actions in response to the lack of water and declining wheat yields. Actions include diversifying farming activities, which includes high value horticulture, such as tomatoes, which tolerate higher salinity levels. Other field crop options include barley, which requires less water than wheat. Another common option is to apply organic fertilizers that have better water retention properties. Despite these options, some farmers still struggle to alleviate the prevailing climatic conditions.

0.6 IMPACTS ON THE DAIRY SUBSECTOR

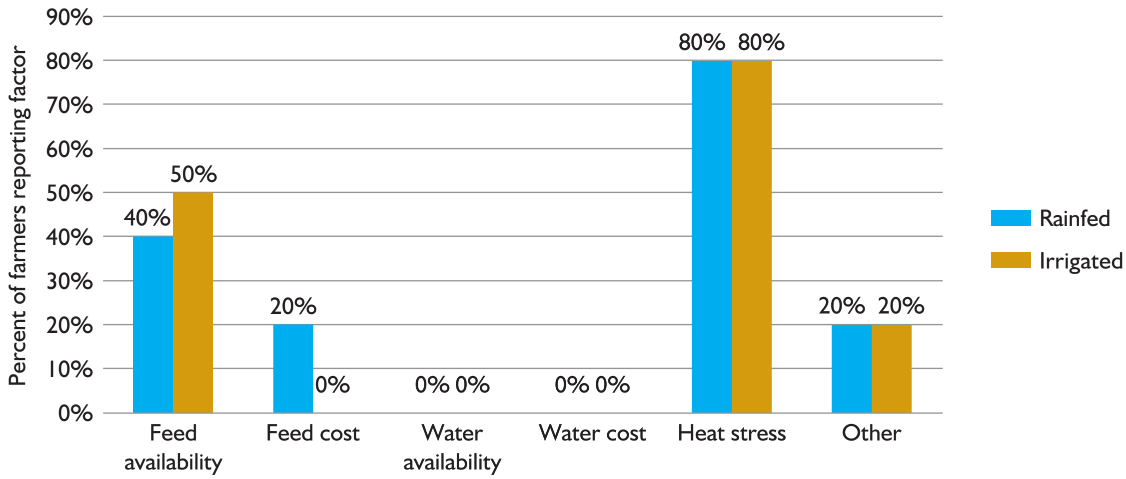
Heat waves caused by extreme temperature shifts also affect dairy production. Milk processors and cheese producers say raw milk suffers in quantity and quality.

[4] Renewable resources are composed of 2,650 Mm^3/year (56%) surface water and 2,150 Mm^3/year (44%) groundwater. Hydraulic infrastructure includes 33 large dams with a total capacity of 2.27 Bm^3, 253 small dams, 837 reservoirs, 5,512 boreholes, and 130,000 wells. In addition, the hydraulic infrastructure includes conveyance facilities to transfer the water from the wetter north to the coast, where uses are concentrated, and to the drier south.

[5] Such modern on-farm irrigation equipment is subsidized in amounts between 40 and 60 percent, depending on farm size.

[6] Nonconventional water resources are estimated at 232 Mm^3/year or 5 percent of resources mobilized.

FIGURE 0.4 Farmer Perceptions of Factors Contributing to Monthly Variability in Milk Quality and/or Quantity



Source: World Bank data.

Note: Multiple responses accepted.

The dairy farmers surveyed for this study say that water availability is decreasing but did not recognize water availability as a challenge to milk production. Heat stress is a widely acknowledged problem for dairy farmers (see Figure 0.4). However, there is too little water available to mitigate the impact of rising average temperatures on livestock. This is especially the case during the summer months. This disconnect indicates a need to train farmers in methods to combat heat stress and teach them about the need for water to grow enough fodder to ensure the availability of feed. None of the producers reported that water availability increased over the past five years, despite increased demand for water.

0.7 GOVERNMENT RESPONSE TO CLIMATE VARIABILITY AND DROUGHT IN THE AGRICULTURAL SECTOR

There was little systematic drought management in Tunisia until the mid-1990s, despite the recurrence of droughts in the 1980s. Law 91-39 designates a permanent national calamities committee related to floods but provides no protocols for managing drought. The first official response came with the successive droughts of 1994–95 and 1997. Then, farmer debt was rescheduled in areas designated as drought-affected, but this provided little support for smallholders, who tend to not have access to credit.

The Ministry of Agriculture, Water Resources, and Fisheries (MoAWRF) officially declares drought in Tunisia (see Box 0.2). The Ministry assesses the drought at the start of the agricultural season based on three main indicator groups: (i) the lack of summer breaking rainfalls (August–October) and a rainy season precipitation deficit higher than 40 percent; (ii) a significant water storage depletion of dams; and (iii) agricultural indicators, such as affected pastures, dehydration of olives, inflation in feed prices, and delayed farmer practices related to soil tillage. Several drought-response measures have been implemented, including fodder provision, surface water and groundwater

BOX 0.2 The Three Steps of Tunisia's Current Drought Management System

Tunisia implemented a national drought management system in response to recurring droughts during the 1980s, 1990s, and 2000s. In 1999, the government published its first guidelines on drought management: *Guide Pratique de la Gestion de la Sécheresse en Tunisie* (Ministere de L'Agriculture, 1999) (*The Practical Guide to Drought Management in Tunisia*). These guidelines outlined methodological approaches, identified principal drought indices, and described drought preparedness and management processes. The MoAWRF/National Meteorology Institute (INM Institut National de al Meteorologie) paper, referred to previously, stated that Tunisia's current drought management system has "three successive steps":

- **Drought Announcement:** The drought announcement takes the form of a decree published in the *Official Gazette of the Republic of Tunisia*. This decree includes a list of affected localities, drought severity levels, and information on subsidies and the rescheduling of credit payments. The announcement is based on hydrological, agricultural, and meteorological indicators observed in different drought-affected regions. These indicators are transmitted by the economic, agricultural, and hydrological districts of relevance for agriculture and water resources as determined by MoAWRF.
- **Warning:** Warnings are transmitted to MoAWRF, which proposes an operational plan to a national commission composed of decision makers and beneficiaries. During the drought, interventions are based on an assessment by the Ministry's technical services for water and agricultural resource status, including reservoir levels and seed and feed stocks. Subsequent measures are implemented according to five different scenarios, which are based on the evolution of the drought in progress. These scenarios and the measures taken under each are summarized in Box 4.5 in chapter 4 below.
- **Action Implementation:** The mentioned national commission, in collaboration with regional and other specialized committees, is responsible for implementing the operational plan.[7] The commission also oversees postdrought activities (Safouene and Lofti).]

Source: Authors.

management, and financial measures related to agricultural credit repayments. However, Tunisia does not offer crop insurance or an emergency drought relief fund. The country also generally lacks drought preparedness and strategic planning.

0.8 PERSISTENT GAPS AND CHALLENGES IN TUNISIA'S DROUGHT MANAGEMENT SYSTEM

Civil society observers, interviewed for this study, say drought interventions have decreased and become less effective over the past 15 years. They argue that the 2000–02 drought interventions were more rapid, decisive, and effective than subsequent ones. The greater effectiveness of past drought management measures was attributed to rapid implementation and the accountability of the officers responsible for them.

Local stakeholders indicate the government's response to drought in recent years has been too little and too late. They argue that two solutions are required in the short term: better drought

[7] According to Nouiri, Nasri, and Tahrani (2014), there are 24 regional commissions (one for each governorate) and four specialized regional commissions for water resource management, livestock safeguards, cereal sector management, and the arboriculture sector.

monitoring and revising current drought plans. These actions would ensure that management priorities, including water allocation, can be implemented quickly and effectively once the onset of drought is identified. Stakeholders also state over the long term there is a need to acknowledge that drought is an important influence on Tunisia's society and economy. As such, there is a need for sector- or community-based risk and drought vulnerability assessments so that resources can be targeted more effectively.

Although the structure of government institutions' roles in drought monitoring and management is now theoretically clear, in practice the responsibilities of each of the pertinent agencies has become blurred. This may be from the large number of directorates involved and their competing interests. Beyond this, many stakeholders indicate they are not sure of the actual mechanisms of decision making regarding drought interventions. Decision making appears to occur opaquely and depends on securing financial resources beyond the planned budget. The high turnover of government staff in recent years has complicated this process through the loss of institutional memory and established personal networks, which were important for implementing management actions in the past.

0.9 POLICY OPTIONS

This study confirms that climate variability, associated droughts, and periods of more intense rainfall are likely to increase in Tunisia, which threatens domestic food and water security. Livelihoods on rain-fed agricultural lands, which account for the largest share of the total area under production, and existing groundwater sources face a growing threat. The risk of food insecurity has important social and economic implications because agricultural exports and imports are directly and, for the most part, adversely affected during drought years. As a result, Tunisia's GDP can be detrimentally affected, which has implications for social well-being. However, lessons from experience can help Tunisia improve drought management.

The government of Tunisia has undertaken measures to address the rising frequency and severity of climate variability and associated drought events. These measures include monitoring and financial relief actions for cereals producers. However, as illustrated in this study, more must be done in the wheat and dairy subsectors.

A review of recent international experience reveals that successful drought interventions are increasingly based on the integrated drought management planning framework. This framework emphasizes drought preparedness and involves three complementary pillars: (i) drought monitoring and early warning; (ii) vulnerability and impact assessment; and (iii) mitigation and response. This report proposes a five-pronged approach to drought resilience in Tunisia, which includes these three pillars as well as planning, drought policy, and risk management more generally.

0.9.1 National Drought Policy

Tunisia lacks a comprehensive national drought management strategy even though many of the basic elements and potential instruments for its implementation are in place. Management activities are largely directed at boosting monitoring capacity. The *Practical Guide to Drought Management in Tunisia*, from 1999 [Pratique de gestion do la secheresse en Tunisia: Approche Methodologie, published by Ministere de L'Agriculture (1999)], describes drought monitoring measures, including a water flow assessment, the standardized precipitation index (SPI), the percentage of normal precipitation, and a

piezometric assessment of groundwater levels. Other activities and a well-defined institutional coordination mechanism are still lacking or only partially in place. The government could develop this mechanism in consultation with public and private sector stakeholders. This includes sectors, governorates, and local geographic areas historically affected by drought. This participatory process could build on the country's drought management experience and be informed by regional and international good practice.

Development of a national drought management strategy that connects drought condition monitoring with management actions is strongly encouraged. This is particularly the case as climate variability affects drought in the short run, and climate change affects drought in the long term. To more effectively address drought conditions in the years and decades ahead, the links among drought, climate change, and climate variability need to be fully integrated into national drought policy and subnational drought response strategies and management plans. Technical assistance, capacity building, and regular information exchange among stakeholders in other countries facing similar challenges could prove helpful. Establishing a regional drought management system (RDMS) would facilitate these interactions.

0.9.2 A General Approach to Drought Planning and Management

Tunisia needs to fully adopt a proactive risk management and adaptation approach rather than continuing with reactive actions to recover from crises. Previously in Tunisia, sound drought plans were developed, but their implementation often has proven difficult. For example, the national drought relief fund is a good approach to relieving financial strain on agricultural producers; however, positive results have not been fully realized. Additionally, technical capacity exists to monitor a range of conditions. More integrated drought monitoring coupled with practical drought mitigation planning and capacity development can lead to early warnings of water shortages. These, other investment activities, and institutional capacity building will increase in importance in the future. The main reason for this is the likelihood of more intense droughts and increasing rural water scarcity in the decades ahead.

Thus, future drought risk and water resource management must go hand in hand and be integrated into agricultural sector planning. Short-term benefits from (authorized and unauthorized) groundwater extraction for agricultural and livestock production should be weighed against long-term costs, which include diminished water supplies and food security. This trade-off means a long-term, cross-sectoral approach is required.

0.9.3 Drought Monitoring and Early Warning Systems

It is a priority to develop scientifically sound climatological drought onset indicators that reflect conditions in Tunisia. Once defined, these indicators could initiate cooperation among various agencies responsible for taking specific drought actions. To facilitate this, an integrated agricultural, hydrological, and meteorological data-sharing platform that connects information from different agencies and is automatically updated could be established. In addition to improved drought monitoring, technical and institutional efforts could be linked to provide a simple and technically sound early warning system. These efforts could include a mechanism to initiate broad coordination before the occurrence of major drought-related impacts. To achieve these objectives, Tunisia can build on its existing drought monitoring and early warning system (see Box 0.3).

BOX 0.3 Building on Tunisia's Current Drought Monitoring and Early Warning System

Drought Monitoring and Early Warning. To monitor weather and water-related conditions, INM (National Institute of Meteorology) and the MoAWRF's General Directorate of Water Resources (DGRE) maintain monitoring stations throughout the country to measure river flow, temperature, precipitation, and groundwater levels. Various indices based on these data are elaborated and disseminated to stakeholders. The density of these national monitoring networks, particularly those measuring river flow, is much higher in the north and center regions, which account for most of Tunisia's agricultural production. Rainfall measurement is especially concentrated around Tunis, and river flow measurement is concentrated in the north. Higher agricultural production in the north and center regions also reflects the considerable difference in surface and groundwater availability across subregions. For example, 60 percent of Tunisia's water resources are concentrated in the north, which is only 17 percent of the national territory. Meanwhile, 18 percent of water resources are in the center, which is 32 percent of the national territory, and 22 percent of water resources are in the south, which is 51 percent of the country's land area.[8] The rainfall measurement network consists of 850 stations and 100 pluviographs. Data (which have been collected since 1969) are published on a daily and monthly basis. The flow monitoring network consists of 60 stations and 74 measurement points with data collected since 1974–75 (Nouiri, Nasri, and Tahrani 2014).

A national drought risk map was developed based on these data and an analysis of the historical patterns of rainfall incidence in various parts of the country. In addition, between 2006 and 2009, the SMAS (Maghreb drought early warning system) regional project, financed by the European Union (EU), was carried out by the Sahara and Sahel Observatory (OSS). This system also covered Algeria and Morocco and had the objective of preventing environmental degradation from droughts. This was done by developing adaptation strategies and an early warning system. It produced and disseminated natural resource vulnerability indicators based on satellite imagery and climate, biophysical, and socioeconomic data. The study, which involved collaboration among three national meteorological institutes, also included climatic zoning and the validation of a climate-related index, the SPI. The SPI was used by other countries for drought monitoring purposes. The SPI's results were synthesized in a drought bulletin.

Source: Authors.

There is also a need to reach out to local experts who can identify local drought signs. This reconciles automatic data generation and modeling with on-the-ground knowledge. It establishes a continual two-way information exchange and validation process for collected data. Local experts can include farmers, extension agents, or other stakeholders in drought-affected areas. This helps mapping accuracy and builds trust and ownership in drought management decision making. More local experts combined with the regular updating of maps also would help national and governorate planning.

Generated data can act as a foundation for drought mitigation and climate change adaptation in rural Tunisia. Such a plan would entail linking drought maps and related data to current operations, scenario planning, seasonal forecasts, and hydrological modeling. Drought model optimization would support infrastructure development and other operations that mitigate drought impacts. This suggests the need to link national and basin-level efforts to anticipate and respond to recurrent droughts with efforts to adapt to broader climate change impacts on agriculture. This includes the need to better train and assist farmers to cope with drought and conserve water effectively.

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[8] Similarly, the North possesses 81 percent of Tunisia's surface water, compared with 12 percent in the Center and 7 percent in the South regions.

0.9.4 Vulnerability and Impact Assessments

Carrying out impact and vulnerability assessments in drought-affected areas can aid in anticipating drought risk. Such assessments help position stakeholders to effectively address impacts. Assessments can be undertaken at varying spatial scales, including at the governorate level. They could inform local drought preparedness plans. This was the case in drought-prone northeast Brazil, where a regional drought monitor was created and is now fully operational. The monitor established a platform for institutional cooperation among technical experts and federal, state, and municipal government agencies.

0.9.5 Drought Mitigation and Response

Adequate financial resources and strong institutional coordination mechanisms that specify agency roles in drought management are needed. The government could designate a single authority to lead drought management decisions and coordinate mitigation activities. Information sharing and establishing triggers to determine what actions are needed in certain locations could be an essential part of this system. A drought governance arrangement would specify institutional roles early or, once drought onset is detected, through the monitoring and early warning systems mentioned. The adoption of a multirisk or drought-specific form of crop insurance for cereals could be considered. A national drought contingency fund could be established. In addition, the budgetary resources need to be clearly identified and allocated in such a way as to obtain the most timely and cost-effective results.

Greater timeliness and transparency in fund allocation to agencies for mitigation and infrastructure investment would help improve the effectiveness of drought responses. This was a problem identified by some interviewees: the perception that past drought mitigation interventions were not as beneficial as they could have been because of inadequate institutional coordination.

Finally, there is a need to recognize the link between more frequent and severe droughts in Tunisia and global climate change and variability. This reinforces the need for Tunisia to integrate its drought management and climate change adaptation policies and instruments.

CHAPTER
ONE

INTRODUCTION

This report explores the impacts of climate variability,[9] including the 2015–16 El Niño and other teleconnections, and of the associated increasingly frequent and severe droughts on the agricultural and livestock sector in Tunisia. It examines past and current efforts by the Tunisian government to address these impacts, including good practices and gaps that still need to be filled. It also makes recommendations for future actions that the country could consider taking to strengthen its approach to drought management, again with a particular focus on agriculture and associated water resource management concerns. Climate-related impacts on wheat and dairy product value chains provide more specific examples of these effects. In carrying out such analysis, this report builds on and updates information for the Middle East and North Africa (MENA) region as a whole and specifically Tunisia that was provided in two earlier World Bank publications: *Adaptation to a Changing Climate in the Arab Countries: A Case for Adaptation Governance and Leadership in Building Climate Resilience* (Verner 2012) and *Tunisia in a Changing Climate* (Verner 2013).

Droughts often have severe impacts on agricultural production and yields and thus on people's livelihoods and welfare. Small-scale farmers, rural workers, and low-income communities are generally the most adversely affected. However, droughts can have significant macroeconomic impacts as well, as national food security needs frequently require increased imports to offset domestic output declines, and the same may be true of crops used for animal fodder. Agricultural exports are also likely to be reduced as a result. Insufficient or highly variable rainfall likewise tends to result in increased pressure on often already declining groundwater resources, especially for irrigated agriculture, which has serious implications for their long-term sustainability. Thus, drought events can have broad and finer scale social, economic, and environmental impacts.

Because the main concern of this report is making drought management more effective in the face of increasing climate variability and change, this introductory chapter briefly describes the nature of droughts and the recommended approach to national drought policy and interventions based on

[9] It is important to differentiate between climate variability and climate change. Climate variability refers to variations in the mean state of precipitation and other climate statistics on all temporal and spatial scales, whereas climate change generally is understood to mean long-term change in the earth's climate, especially a change attributable to an increase in the average atmospheric temperature, which is often commonly referred to as global warming. Drought events are examples of climate variability but also appear to be increasing in frequency and severity as the result of global warming.

evolving international experience. This experience was reviewed for selected developed and developing countries, including elsewhere in MENA,[10] as part of the current study and has been summarized in a background paper (Redwood 2017). This experience is also reflected in recently published World Bank–supported books on drought management challenges and opportunities in sub-Saharan Africa (Cervigni and Morris 2016) and Brazil (De Nys, Engle, and Magalhães 2017).

After this Introduction, the balance of the report is divided into four chapters. Chapter 2 and its annexes consider recent evidence regarding climate change and variability and drought in the MENA region and in Tunisia in particular, including the possible impact of the recent El Niño and other relevant climate phenomena (known as "teleconnections"). Chapter 3 and its annexes examine the impact of recent droughts on the agricultural sector in Tunisia, including their effects on two economically important agricultural value chains (dairy products and olives), which are the subject of other World Bank analytical work. Chapter 4 describes the evolution and nature of Tunisia's efforts to address droughts with a focus on the agricultural sector, and Chapter 5 presents the study's principal suggested policy options.

The nature of droughts. A drought can be defined as "an extended period of deficient precipitation compared to the statistical average for a particular region which results in water shortages for some activity, group, or environmental sector" (FAO and NDMC).[11] However, numerous definitions exist. Some of the main alternatives are presented in Box 1.1.

According to the United Nations Food and Agriculture Organization (FAO) and other specialists, there are various types of droughts and differing ways of measuring them:

- **Meteorological drought** is defined by the lack of precipitation over a region for a period of time. Analyses can concentrate on monthly precipitation (for example, Gibbs 1975) or cumulative precipitation shortages (for example, Estrela, Penarrocha, and Millan 2000).
- **Hydrological drought** results from a period with inadequate surface and subsurface water resources for established water uses. Streamflow data are generally applied to hydrological drought analysis (Dracup, Lee, and Paulson 1980; Clausen and Pearson 1995;). Geology is one of the main factors influencing hydrological droughts (Vogel and Kroll 1992). Reservoir levels are also an important consideration.
- **Agricultural drought** refers to periods with declining soil moisture and consequent crop failure or when there is insufficient soil moisture to meet the needs of a particular crop at a particular time. This typically occurs after a meteorological drought but before a hydrological one. Because crop water demands depend on specific plant characteristics, stage of growth, type and state of soil, and weather conditions, several drought indices, based on a combination of factors (for example, precipitation, temperature, and soil moisture) have been devised.
- **Socioeconomic drought** occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply (American Meteorological Society 2004) or when human activities are affected by reduced precipitation and related water availability, which associates human activities with elements of meteorological, agricultural, and hydrological drought (FAO, 2013).

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[10] Specifically, recent drought management experience was reviewed for Australia, Brazil, India, Iran, Jordan, Lebanon, Mexico, Morocco, Spain, Tunisia, and the United States.

[11] See, for example, FAO and National Drought Mitigation Center (NDMC), *The Near East Drought Planning Manual: Guidelines for Drought Mitigation and Preparedness Planning*, Rome, 2008, pg. 5, and FAO, *Drought Facts*, Rome, 2013.

BOX 1.1 Alternative Definitions of Drought

There is no universal definition of drought, leading to possible confusion regarding how to predict droughts, individuate them while they occur, and respond to them promptly. One of the problems associated with drought is that the nature of water availability and differing demands in various parts of the world have historically resulted in many different views and definitions of drought. However, two main classes of drought definitions exist (Mishra and Singh 2010):

1. Conceptual definitions, which are stated in relative terms (for example, drought is a long dry period). It is obvious that the understanding of a long-term period will differ in different areas of the world, such as the northeastern United States, southern Italy, or the Sahel.
2. Operational definitions, which attempt to identify the onset, severity, and termination of drought periods, leading to analysis of drought frequency, severity, and duration for a given return period.

Mishra and Singh (2010) present a number of drought definitions to show how different they can be:

- drought is "a significant deviation from the normal hydrologic conditions of an area" (Palmer 1965);
- a drought hazard is "the percentage of years when crops fail from the lack of moisture" (FAO 1983);
- drought is a "sustained, extended deficiency in precipitation" (World Meteorological Organization 1986);
- drought is "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems" (United Nations Secretariat General, 1994);
- drought is "an extended period—a season, a year, or several years—of deficient rainfall relative to the statistical multi-year mean for a region" (Schneider 1996).

Most of the time, but not always, meteorological drought will be the trigger for (and followed by) other types of drought. In addition, some experts refer to a more specific type of hydrological drought as groundwater drought, which can be defined by the decrease of groundwater level (Eltahir and Yeh 1999), of groundwater recharge (Marsh et al. 1994), or of groundwater discharge (Peters et al. 2001). Overexploitation may create a groundwater drought and is a problem especially in arid and semiarid zones where groundwater has formed over long time scales because of little to no precipitation throughout the year. This is of relevance to countries in the MENA region, including Morocco, because one of the typical responses of farmers to agricultural drought, especially those depending on irrigation, is increased exploitation of groundwater, which is already in comparatively scarce supply.

Over the past few decades, droughts have become more frequent and intense worldwide and are affecting both developed and developing countries. Projections by the Intergovernmental Panel on Climate Change (IPCC) indicate that droughts are likely to become even more so in the future because of global climate change.[12] This source affirms that, although regional droughts have occurred in the past, the widespread extent of drought conditions in various parts of the world is broadly consistent with the

[12] The IPCC Working Group I's fourth report (IPCC, 2007) on the Physical Science Basis, for example, stated the following with respect to climate change and drought: "Intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most sub-tropical and mid-latitude regions), precipitation intensity is projected to increase, but there would be longer periods between rainfall events. There is a tendency for drying of the mid-continental areas during summer, indicating a greater risk of drought in those regions."

expected changes in the hydrological cycle under global warming. Droughts in some areas are often more severe in El Niño years, such as 2016, although the certainty and severity of their effects vary in accordance with a country's geographic location as is further assessed in the next chapter.

Drought Impacts. Droughts, which have also been appropriately described as "a slow, creeping natural disaster," have significant direct and indirect economic, social, and environmental impacts. They particularly affect agriculture and related sectors, such as livestock, forestry, and inland fisheries, because of the strong reliance of those sectors on surface and subsurface water supplies. Direct generic impacts of drought include (i) reduced crop, rangeland, and forest productivity; (ii) reduced water levels in rivers, lakes, and reservoirs and thus increased water shortages; (iii) increased fire hazards; (iv) damage to wildlife and fish habitats; (iv) higher livestock and wildlife mortality rates; (v) insect infestations; (vi) increased plant disease; and (vii) greater wind and soil erosion. Increased erosion often leads to increasing desertification, which is defined as "the degradation of land in arid, semi-arid, and other areas with a dry season caused primarily by over-exploitation and inappropriate [land] use interacting with climate variance" (FAO and NDMC, 2008). Potential indirect impacts include: (i) reduced income for farmers and agribusinesses; (ii) increased prices for food and other primary products; (iii) rural unemployment; (iv) lower tax revenues; (v) increased crime and insecurity; and (vi) increased migration to urban areas and elsewhere.

Although the incidence and intensity of droughts appear to be increasing worldwide in association with climate change, developing countries are generally more vulnerable than higher income ones to the adverse effects of drought. Among the reasons for this is that dry-land populations tend to be concentrated in developing countries and employed to a relatively greater extent in the agricultural sector. This is particularly the case in lower-middle- and low-income countries such as many of those in sub-Saharan Africa, South Asia, and MENA, where agriculture is responsible for a comparatively high share of total freshwater extraction, which clearly varies by country income level (see Table 1.1). Drought-related economic losses likewise tend to be significantly higher as a proportion of gross national income (GNI) in the developing world, according to FAO, 2013. In general, developing nations and their poor rural populations in particular are comparatively less well prepared to confront droughts and their impacts.

International Response. The international community has increasingly recognized the economic, social, and environmental risks associated with droughts as well as the likelihood that their future impacts will be exacerbated by climate change. Among other responses, this led to the convening of a High Level Meeting on National Drought Policy (HMNDP) by the World Meteorological Organization (WMO), the United Nations Convention to Combat Desertification (UNCCD), and FAO in collaboration with other UN agencies in Geneva in March 2013.

The Final Declaration from this Meeting encouraged all governments "to develop and implement National Drought Management Policies, consistent with their national development laws, conditions, capabilities and objectives" (HMHDO, 2013), accompanied by the following:

- Development of proactive drought impact mitigation and preventive and planning measures; risk management; fostering of science, appropriate technology, and innovation; public outreach; and resource management.
- Promotion of greater collaboration to enhance the quality of local/national/regional/global observation networks and delivery systems.

TABLE 1.1 Per Capita Gross National Income (GNI), Rural Population, and Share of Labor Force in Agriculture and Agriculture as a Share of Water Withdrawal for Selected Countries, Regions, and Income Groups

Country/Region	Per Capita GNI (US$) (World Bank Atlas Method)	Rural Population Share (%)	Share of Labor Force in Agriculture		Agriculture as a Share of Total Freshwater Withdrawal (%)
			Male (%)	Female (%)	
United States	55,230	18.6	2.3	0.9	40
Spain	29,390	20.6	6.0	2.1	64
Australia	64,600	10.7	3.5	1.7	66
India	1,570	67.6	NA	NA	90
Mexico	9,870	21.0	18.8	3.7	77
Brazil	11,790	14.6	17.5	10.7	60
Iran	7,120	27.1	NA	NA	92
Jordan	5,160	16.6	NA	NA	65
Lebanon	10,030	12.3	NA	NA	60
Morocco	3,070	40.3	NA[a]	NA[a]	88
Tunisia	4,230	33.4	NA[a]	NA[a]	80
North America	54,879	18.5	2.3	0.9	38
Europe and Central Asia	26,424	29.3	8.6	7.1	36
Latin America and Caribbean	9,912	20.4	17.9	8.1	72
East Asia and Pacific	9,731	44.3	NA	NA	72
Middle East and North Africa	8,722	36.3	NA	NA	85
Sub-Saharan Africa	1,646	62.8	NA	NA	81
South Asia	1,496	67.4	NA	NA	91
Low Income	628	70.2	NA	NA	90
Lower Middle Income	2,018	61.5	NA	NA	88
Upper Middle Income	7,926	38.2	NA	NA	49
High Income	38,301	19.3	4.0	2.2	43

Sources: World Bank *Little Green Data Book*, Washington, D.C., 2016; World Bank, *World Development Indicators*, Washington, D.C., 2016.
[a] Gender disaggregated information was not available (NA) in the *World Development Indicators* for the MENA countries and India for 2013–16. However, according to this source, 37.2 percent of the total Moroccan labor force in 2014 and 15.3 percent of that in Tunisia in 2013 was employed in the agricultural sector.

- Improvement of public awareness about drought risk and preparedness for drought.
- Consideration, where possible within the legal framework of each country, of economic instruments and financial strategies, including risk reduction, risk sharing, and risk transfer tools in drought management plans.
- Establishment of emergency response plans based on sound management of natural resources and self-help at appropriate governance levels.
- Integration of drought management plans with local and national development policies.

After release of the HMNDP Final Declaration (2013) WMO and the Global Water Partnership (GWP), together with the National Drought Mitigation Center (NDMC) at the University of Nebraska, established an integrated drought management program (IDMP), which soon thereafter published the rationale and a set of guidelines for development of a national drought policy (NDP) or strategy (NDS). This document lays out a 10-step process for countries to follow to prepare an NDP or NDS, which is summarized in Box 1.2. This useful framework, which emphasizes the importance of stakeholder participation, also can be used to assess the extent to which specific countries have currently progressed along the recommended path that contains three main pillars: (i) drought monitoring and early warning; (ii) vulnerability and impact assessment; and (iii) mitigation and response.

Per the IDMP document, governments have traditionally responded to droughts primarily with emergency assistance measures that often are of an ad hoc nature. However, it argues that this approach is "seriously flawed" from the standpoint of vulnerability reduction because the recipients of government support "are not expected to change behaviors or resource management practices as a condition of the assistance." Instead, it affirms that governments could develop national drought policies/strategies and preparedness plans that focus on risk reduction. It recommends that such documents should include organizational frameworks and operational arrangements and that they should be developed "in advance of drought and maintained between drought episodes by governments or other entities" with the complementary objective of generating "improved coordination and collaboration within and between levels of government, stakeholders in the primary impact sectors, and the plethora of private organizations with a vested interest in drought management (i.e., communities, natural resource or irrigation districts or managers, utilities, agribusinesses, farmers' organizations, and others)" (WMO and GWP 2014).

The WMO and GWP have developed a useful checklist of historical, current, and potential drought impacts and broken them down into economic, environmental, and social categories. These impacts

BOX 1.2 Proposed Steps in the National Drought Policy/Strategy and Preparedness Process

1. Appoint a national drought management policy/strategy committee.
2. State or define the goals and objectives of a risk-based national drought management policy/strategy.
3. Seek stakeholder participation; define and resolve conflicts between key water use sectors, considering transboundary implications.
4. Inventory data and financial resources available and identify groups at risk.
5. Prepare/write the key tenets of the national drought management policy/strategy and preparedness plans, including the following elements: monitoring, early warning and prediction, risk and impact assessment, and mitigation and response.
6. Identify research needs and fill institutional gaps.
7. Integrate science and policy aspects of drought management.
8. Publicize the national drought management policy/strategy and preparedness plans and build public awareness and consensus.
9. Develop education programs for all age and stakeholder groups.
10. Evaluate and revise national drought management policy/strategy and supporting preparedness plans.

Source: WMO and GWP (2014).

include the following subcategories, which are of particular relevance for the agricultural, livestock, forestry, and fisheries sectors and for rural areas more generally:

- Economic
  - Losses from crop production
  - Losses from dairy and livestock production
  - Losses from timber production
  - Losses from fisheries production
  - Income losses for farmers and others directly affected
  - Unemployment from drought-related production declines
  - Decline in food production/disrupted food supply
  - Increased groundwater depletion, land subsidence
  - Decreased land prices
- Environmental
  - Damage to plant species
  - Increased number and severity of fires
  - Wind and water erosion of soils
  - Reservoir, lake and drawdown or reduced water levels (including farm ponds)
  - Water quality effects (for example, salt concentration, increased water temperature, and so forth)
- Social
  - Reductions in nutrition (for example, high-cost food limitations, stress-related dietary deficiencies)
  - Increased conflicts, including with respect to water use, and so forth
  - Inequity in drought impacts
  - Reduced quality of life, changes in lifestyle in rural areas
  - Population migration from rural areas.

Overview of the Tunisian Case. Long-term climate change and shorter-term recurrent climate events, such as ENSO, NAO, and MO, are making water-scarce countries such as Tunisia more vulnerable and their dry-land agriculture even drier. As a result, an existing problem for farmers is becoming even worse as temperatures rise and rainfall becomes more sporadic. Tunisia's farmers are experiencing and will continue to be subjected to increasing climate variability. Droughts are one of the most significant outcomes of these climate phenomena, and farmers are particularly vulnerable to them because droughts negatively affect key rain-fed crops, such as wheat and barley, and livestock.

Agriculture is important for rural communities and the overall Tunisian economy because approximately 20 percent of the population is employed in this sector, which contributes, on average, 10 percent of the country's GDP and 10 to 12 percent of its total exports. Wheat and other rain-fed crops are among the crops most affected by climate variability, and they are critical for food security and livestock survival in the country. The increasingly adverse impacts of climate change-associated droughts translate into a contingent liability for the Tunisian macro economy, including GDP growth and the balance of payments, as agricultural and agro-industrial outputs and exports decrease and food and fodder imports need to increase to meet domestic needs. Therefore, the current report suggests additional action with respect to integrated drought management (IDM) on top of what the government is already doing.

Multiyear drought and general rainfall variability is a key issue for agriculture in Tunisia. Water availability is the most important underlying issue because surface water is becoming scarcer, and this has led farmers to pump more groundwater to supplement irrigation of crops and fruit trees as a way to adapt to the changing climate. Such practices necessitate improved water resource management and supervision and better enforcement of existing laws and regulations. International experience in developed and developing countries reveals that such actions can be an effective way of addressing short- and long-term water scarcity problems.

Although the negative effects of ENSO are clearly important from a global perspective, based on original research, this study finds that they were less important than other teleconnections with respect to the most recent drought (2015–16) experienced in Tunisia and elsewhere in the MENA region. This report also examines two important crops (wheat and dairy products) to determine how and how well they are adapting to climate variability and change. The adaptation pathways chosen to secure and increase productivity and incomes in the agricultural sector rightly focus on tree crops that are generally more resilient than field crops. However, improved water management is also an essential part of this adaptation plan.

With improved collaboration across and coordination among public sector institutions and better information access and sharing, farmers can make more effective investments and agribusinesses can become more profitable, which together will contribute to greater income and employment. In addition, the government could consider elevating and revising its current integrated drought management strategy (IDMS) into a more formal integrated drought management policy, as recommended by international organizations, including the UN Food and Agricultural Agency (FAO) and the World Meteorological Organization (WMO), and undertaken by numerous countries, including Australia and Mexico. Taking such actions will help Tunisia reduce the contingent liability associated with increasing climate variability and drought and achieve greater and more sustainable impacts for farmers and the national economy.

CHAPTER
TWO

CLIMATE VARIABILITY AND DROUGHT IN MENA AND TUNISIA

This chapter reviews the scientific evidence about the increasing incidence of climate variability and drought in recent years in Tunisia. In doing so, it focuses on the contribution of several important teleconnections, including the strong El Niño Southern oscillation (ENSO) that affected climate conditions in various parts of the world in 2015–16. It also considers the implications of increasing climate variability and drought for the agricultural sector in Tunisia, the impacts of which are examined in greater detail in Chapter 3.

2.1 OVERVIEW

Climate in Tunisia is changing, and the country has experienced a large annual mean temperature increase of 0.5°C to 0.75°C per decade since about 1970. This is well above the global mean trend of ~0.15°C per decade over the same period. Recent years have been particularly warm, and several temperature records have been broken. Along with the recent warm years, several dry wet seasons have occurred. Although no long-term trend in precipitation amounts appears to be detectable, the recent strong year-to-year fluctuations in rainfall have resulted in several years during the past decade in which low precipitation amounts have led to severe water scarcity or even droughts. This climate variability, together with its impacts on the agricultural sector, is discussed in greater detail later in this chapter and in the next. Annex 2.1 provides background information on recent climate variability and changes in the MENA region more generally.

With the concurrent strong El Niño in 2015–16 and drought conditions in parts of the MENA region, it has been hypothesized that the occurrence of El Niño can be seen as an early warning mechanism for droughtlike conditions, including in Tunisia. However, the existence of a strong link between ENSO and drought in Tunisia cannot be confirmed with analysis of a long-time series of various climate records. A monthly breakdown shows that most of the precipitation and the strongest correlations are in August. A positive El Niño phase can influence heavy August showers, which can refill water resources but also have a negative, disruptive impact on soils. On the other hand, as discussed later, the Mediterranean oscillation (MO) seems to be the most relevant teleconnection for winter precipitation, affecting all the country. A positive precipitation anomaly is found for the positive MO phase (and vice versa

for the negative phase). For more definitive results, studies of greater complexity that take correlations between these different modes of climate variability and their interplay with regional geographical features into account are needed.

Climate projections indicate that Tunisia will continue to experience warming well above the global mean rate. Projections also indicate that winter precipitation will be reduced as warming increases. Even with no change in precipitation, evaporation will increase because of rising temperatures, and consequently, surface soil moisture will tend to decrease. Similarly, the availability of water for irrigation using mountain streams and reservoirs will continue to be stressed and at an increasing rate. Taken together, the chances are high that widespread drought conditions will occur more frequently and even become more severe in Tunisia, challenging local agriculture.

Although drought is the principal focus of the current study, it is not the only climate-related risk to agriculture. As the climate warms, there is an increased risk of flash floods from heavy precipitation, resulting in landslides and loss of infrastructure, crops, and arable land. Likewise, dry conditions enhance the risk of wildfires and the associated loss of property and crops. Agricultural practices in Tunisia thus need to be able to better respond to the long-term trends associated with global warming and teleconnections, such as MO and ENSO, considering that substantial annual to decadal fluctuations will occur on top of the mean overall warming trend. Large-scale international efforts to improve long-term predictions are ongoing. Thus, it remains essential for Tunisian authorities to be aware of and engaged with the specialists working on these issues. If the precision of ENSO and MO predictions regarding seasonal over multiyear to decadal time scales can be improved, planning crop selections and the timing of their planting can be enhanced.

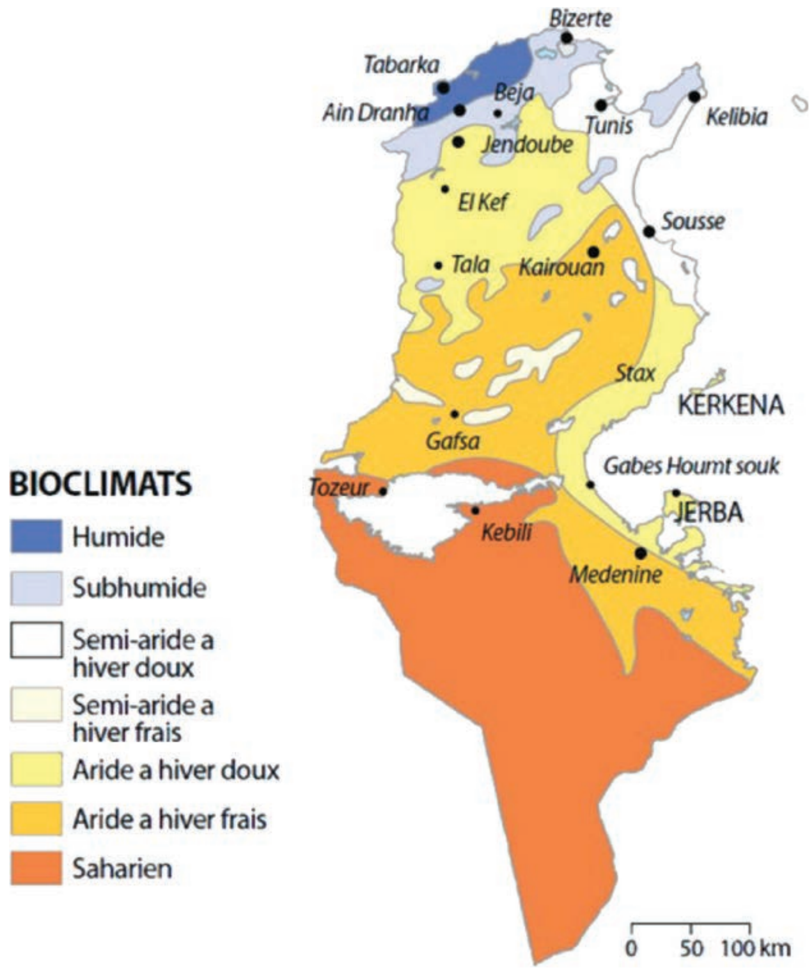
2.2 THE CLIMATE OF TUNISIA

Most of northwest Africa's rainfall occurs during the period from October to May as the result of extratropical weather system incursions from the Atlantic Ocean and Europe bringing cold air and cloudiness. The typical rainfall distribution is characterized by a positive gradient from south to north and is affected by the topographic influence exerted by the Atlas Mountains. The dry season extends from June to early September, influenced by hot, extremely dry air originating from the Sahara Desert. Nevertheless, some convective clouds develop occasionally during the dry season when subtropical maritime air masses converge in the region. Summer is generally dry and hot. Daily maximum temperatures exceeding 40°C are a common feature of the continental areas.

The fertile areas of the Mediterranean coastline are hydrated by their proximity to the sea. The Atlas Mountains stretch from the Atlantic coast of Morocco to Tunisia, where the range terminates facing the northern and eastern coasts. These mountains form a barrier that wrings water from the clouds because of the effect of ascending moist air being cooled and released as precipitation. This rain (and on rare occasions snow) creates rivers and streams that run through the mountain villages and provide water for the valley farms. A more detailed view of the climate of Tunisia is depicted in Figure 2.1, which summarizes FAO's representation of climate and agroecological zones of Tunisia.

The Tunisian climate is largely Mediterranean, characterized by hot dry summers and cool moist winters that limit the growing period. Precipitation is irregular, and rainfall varies considerably from

FIGURE 2.1 Bioclimatic Zones of Tunisia



Source: You et al. 2016.

north to south. Tunisia is divided into four large geographical units: northern, eastern, central, and southern regions. According to Emberger (1960), there are five bioclimatic zones going from the most arid to the most humid based on rainfall levels (Table 2.1). However, rainfall is not the only bioclimatic determinant. Temperature, especially winter temperature, is important. This is governed not only by altitude but also by the degree of continentality. Inland meteorological stations register relatively hotter summers and colder winter than areas that benefit from the buffering effects of the sea. Therefore, bioclimatically the country is also divided into areas of warm, cool, and cold winters. Depending on the annual rainfall, there are four main agricultural regions, which are summarized in Table 2.2.

The Mediterranean-like climates of the world are among the most vulnerable to the pressures from ongoing and projected future global climate change. This has been pointed out in several IPCC reports (Christensen et al. 2007, 2013). It is also reflected in the temperature trends experienced in the

TABLE 2.1 The Bioclimatic Zones of Tunisia

Annual Rainfall (mm)	Bioclimatic Strata
800–1,200	Humid
600–800	Subhumid
400–600	Semiarid
100–400	Arid
20–100	Desert (Saharan)

TABLE 2.2 The Agroecological Zones of Tunisia

Zone	Annual Rainfall (mm)	Agriculture and Land Use
North	500 < Rain < 1,000	Natural forest, *maquis* (shrubland) and grazing areas; possibility of rain-fed crops: annual crops and horticulture
Dorsal[13]	400 < Rain < 500	Forest, *maquis* and rangelands but fragile; possibility of cropping, but with risky annual crops and tree crops adapted to edaphic and topographic conditions
Center	200 < Rain < 400	Forest and *maquis* fragile in favorable edaphic and topographic conditions; rangelands are fragile; possibility of cropping but with risky annual crops and tree crops
South	Rain < 200	Fragile steppe in favorable edaphic and topographic sites; rangelands easily degraded; rain-fed agriculture is locally possible with good management of runoff

region. Annex 2.2 presents the annual mean temperature trend for four meteorological stations in Tunisia, with a reasonably complete time span coverage to assess the temperature trends. Tunis has the most complete series and spans more than 100 years of data. The most recent data are for 2016. However, as is evident from the IPCC's Assessment Report 5 (AR5; Hartmann et al. 2013), Tunisia has experienced an annual warming trend of 0.5°C to 0.75°C per decade since about 1970, which is well above the global mean trend of ~0.15°C per decade for the same period. It should be noted, however, that temperature trends may differ substantially because of local conditions, and the overall trend across the entirety of Tunisia may actually have been realized, as depicted differently from what has been realized at these five geographically well-distributed stations. Precipitation data from representative meteorological stations are presented in Figure 2.2.[14]

Although temperature changes worldwide appear to be evolving in a way that is largely coherent with the global mean temperature (although with varying amplitude), precipitation trends and long-term changes are much less clear. Rainfall variations are often a complex consequence of changes in large-scale drivers (for example, radiative forcing related to an enhanced greenhouse effect), local and regional feedbacks that may operate in opposing directions. For instance, Hartmann et al. (2013) reported that most of the Mediterranean region experienced a drying trend between 1950 and 2010. But station data from Tunisia (although not entirely complete) are inconclusive in confirming such an overall trend (also shown in Annex 2.2). Rather, the time series indicates large interannual and decadal variations that cannot directly be linked to the global or even regional warming trends.

2.3 DROUGHTS AND THEIR CAUSES IN TUNISIA

Shortage of available water continues to be a significant constraint for economic and social development in Tunisia. This is the result of both natural conditions (aridity and drought) and poor water management practices and decision making (water scarcity and desertification) leading to increased water insecurity (see Figure 2.3). Political unrest, economic dislocation, a growing population, lack

[13] The Tunisian Dorsal is the southwest-northeast–trending mountain range that is an extension of the Saharan Atlas of Algeria; it tapers off in the direction of the Sharīk (Cape Bon) Peninsula in the northeast.

[14] Temperature information can be accessed from the Tunisian National Institute of Meteorology website: http://www.meteo.tn/htmlen/accueil.php

FIGURE 2.2 Monthly Mean Precipitation (in millimeters) for Nine Quality Checked Data Series, 1961–90, Representing the Tunisian Climate

of international agreements over shared water resources, and poor water management all pose threats to the country against a background of increasing risks from current and predicted meteorological and climatological characteristics of the region (Gleick 2014).

Over the last decade, the growth in population, through both natural increase and forced migration, together with the expansion of agricultural, energy, and industrial activities, has elevated the demand for water at a time of growing contamination of water supplies and limited investment in water and sanitation services. Rapid urbanization also contributes to water scarcity because the development of adequate infrastructure to respond to human needs frequently has not kept up with the growth in population. At the same time, natural water availability is affected by aridity and droughts, particularly in more humid and semiarid areas where agriculture is predominantly rain-fed. Aridity denotes a permanent or semipermanent local condition in which precipitation is reduced, as are natural water resources. In addition, many parts of Tunisia have experienced increasing salinity of both groundwater and soils in recent decades.

FIGURE 2.3 Limited Water Availability across Different Time Scales and Causes Are Defined Using Specific Terms

	Short/Mid Time Scale or Temporary	Long Time Scale or Quasi-Permanent
Natural	Drought	Aridity
Human-made	Water Scarcity	Desertification

Source: Pereira, Oweis, and Zairi 2002; Van Loon and Van Lanen 2013.

Beyond increasing aridity, Tunisia is projected to experience an increased risk of summer drought. Dry lands are particularly prone to drought because their rainfall amounts critically depend on a few events, and there often is little stored renewable water available to offset resource deficits (Sun et al. 2006). These regions also typically show strong spatial and temporal variability in rainfall. A drought is distinct from a heat wave because the latter typically occurs over the time scale of a week, whereas droughts persist for months or years (Chang and Wallace 1987). Droughts are slower to develop, longer lasting with impacts increasing over time, and less predictable than other climate extremes such as floods. Furthermore, drought is not necessarily related to an increase in temperature. However, several recent research papers have shown that climate change is resulting in increased drought frequency and intensity in the Mediterranean region, especially because of reduced winter rainfall and increasing evapotranspiration (Mathbout and Skaf 2010; Romanou et al. 2010; Hoerling et al. 2012).

Teleconnections. Understanding why droughts occur is one of the first steps to being able to predict future events and act to prevent negative impacts on people's incomes and well-being. The underlying atmospheric conditions that cause drought are large-scale, high-pressure systems over an area for a period of time that prevent low-pressure, rain-bearing frontal systems from moving into the area or for convectional uplift conditions to persist. The changes in large-scale atmospheric dynamics that bring about these localized conditions are still poorly understood, including the role of the influences known as teleconnections (from the Greek word for "faraway," and the English word "connection"). They are defined as recurring and persistent large-scale patterns of pressure and circulation anomalies over vast geographical areas or, more simply, as atmospheric interactions between widely separated regions of the earth (Glantz 1994).

Teleconnections can last from weeks to months at a time. They can appear for several consecutive years, so they can play a major role in interannual and interdecadal atmospheric variability. Because they can affect temperature, precipitation, storm tracks, and jet stream location and intensity, they often are responsible for abnormal weather patterns, simultaneously affecting distant areas (Mo and Livezey

1986; Barnston and Livezey 1987; Barnston, Livezey, and Halpert 1991; Christensen et al. 2013). Different teleconnections are found around the globe, and their strengths and phases are often characterized by defining particular indexes; this is discussed in greater detail later. The most important teleconnections for the MENA region are ENSO, the North Atlantic oscillation (NAO), and the Mediterranean oscillation (MO).

El Niño is the best-known coupled ocean-atmosphere phenomenon that causes global climate variability on seasonal to interannual time scales (Wolter and Timlin 2011). Although it clearly influences areas in Asia and Africa, as well as North and South America, ENSO's impact on North Africa is generally weak. Simulations by Merkel and Latif (2002) using a fully coupled climate model suggest that El Niño could weaken the North Atlantic mean meridional pressure gradient, causing a southward shift of the North Atlantic storm track that, in turn, has been shown to produce a weakening of the NAO and wetter conditions over central Europe and the western Mediterranean (Hurrell and van Loon 1997). Reanalysis data have shown a possible negative correlation between ENSO and precipitation in northeastern Tunisia (Mariotti, Zeng, and Lau 2002). Additional research has shown possible links between European and Mediterranean climate and ENSO (Lloyd Hughes and Saunders 2002; Shaman 2014). However, evidence remains sparse, and not much work has been carried out or is available in the literature with respect to the North African response to ENSO and its relationship with other teleconnections influencing the region.

NAO is among the most prominent teleconnection patterns known to affect large parts of the MENA region throughout the year (Barnston and Livezey 1987). The NAO consists of a north-south dipole of air pressure anomalies, with one center located south of Iceland and the other center of opposite sign situated over the Azores (between 35°N and 40°N). The positive phase of the NAO indicates below-normal pressure across the high latitudes of the North Atlantic and above-normal pressure over the central North Atlantic, the eastern United States, and western Europe. The negative phase indicates an opposite pattern of pressure anomalies over these regions.

Observations, reanalysis, and climate reconstruction over decades and centuries suggest that NAO is the dominant influence on large-scale patterns of winter precipitation, river flow, and surface temperatures across the Middle and Near East. NAO is also an important driver for western and southern Mediterranean precipitation. Winter rainfall over southern Europe and North Africa has declined since the 1970s because of a strongly positive phase in the NAO. The North Atlantic Oscillation index (NAOI) is calculated through a technique known as the rotated principal component analysis (RPCA) procedure (Barnston and Livezey 1987) applied to monthly mean standardized 500-mb height anomalies obtained from the Climate Data Assimilation System (CDAS) in the 20°N to 90°N region between January 1950 and December 2000. For each month, teleconnection indexes (which include NAO and other relevant modes in this region) are calculated as the solution to the least squares system of equations that explains the most spatial variance of the observed standardized height anomaly field.[15] The Mediterranean and Western Mediterranean oscillations (MO and WeMO), which are described in Box 2.1, also affect parts of the MENA region, especially Tunisia.

Analyzing possible links between teleconnections and Tunisian drought. There has been little analysis of the climatology of droughts in Tunisia or their connections to known atmospheric variations. Thus, in the current study, correlation analysis was undertaken to examine any links between precipitation anomalies in Tunisia and teleconnections from atmospheric oscillatory

[15] For more information on the RPCA technique, see www.cpc.ncep.noaa.gov/data/teledoc/teleindcalc.shtml

BOX 2.1 The Mediterranean and Western Mediterranean Oscillations (MO and WeMO)

Conte, Giuffrida, and Tedesco (1989) introduced the concept of MO, studying the presence of synchronized, but opposed, atmospheric behavior between its eastern and western subbasins. The low-frequency pattern of the MO produces opposed anomalies between the extremities across the basin, affecting pressure, temperature, and precipitation regimes. The influence of the MO on Mediterranean climate variability has been studied by many researchers (Corte-Real, Zhang, and Wang 1995; Palmieri et al. 2001; Palutikof et al. 1996; Piervitali et al. 1997; Kutiel and Paz 1998; Maheras, Xoplaki, and Kutiel 1999; Xoplaki 2002; Baldi et al. 2004). With specific reference to precipitation, research has highlighted that the MO is the most important low-frequency driver (Douguédroit 1998; Maheras, Xoplaki, and Kutiel 1999; Dünkeloh and Jacobeit 2003). Several methods have been used to measure the MO. The Mediterranean Oscillation index (MOI), given by Conte, Giuffrida, and Tedesco (1989) and Palutikof et al. (1996), is defined as the normalized pressure difference between Algiers (36.4°N, 3.1°E) and Cairo (30.1°N, 31.4°E). MOI data are calculated through 16-point Bessel interpolation of NCEP/NCAR reanalysis of pressure data and provided by the Climate Research Unit (CRU).

Martin-Vide and Lopez-Bustins (2006) proposed a new regional teleconnection pattern, the Western Mediterranean Oscillation (WeMO), initially to try to explain the poor relationship between the weather patterns in the eastern Iberian Peninsula and the NAO. WeMO. It was defined as the difference in pressure between the Po plain, in the north of the Italian peninsula, and the Gulf of Cadiz, in the southwest of the Iberian Peninsula, with its positive phase being when pressure in Cadiz is higher than that in the Po region. WeMOI has been used in studies to explain daily time scale to heavy rainfall events (Martin-Vide and Lopez-Bustins, 2006; Martin-Vide et al. 2008), sea breeze occurrence (Azorin-Molina and Lopez-Bustins 2008), sunshine variability (Lopez-Bustins and Sanchez-Lorenzo 2006), and winter rainfall trends (Oliva et al. 2006; Lopez-Bustins et al. 2008). These teleconnections or circulation indices will be used in detail later in this chapter to attribute the likely large-scale cause for agricultural droughts in Tunisia.

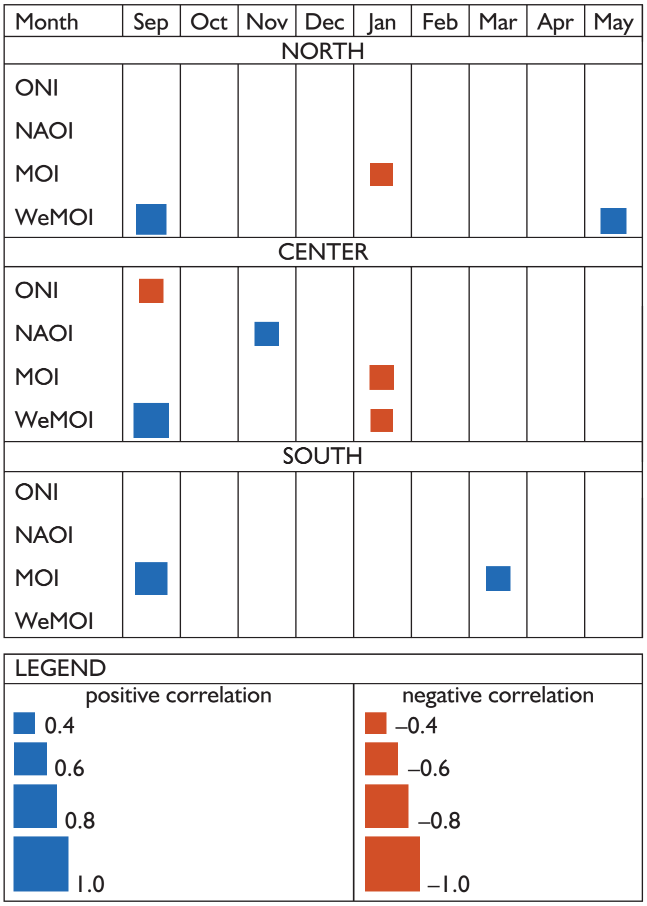
systems suspected of influencing the region. The focus was on the droughts in Tunisia from 1990 to 2014 (the available meteorological station data) and their correlation with ENSO,[16] NAO, MO, and WeMO. [17]

The country was divided into two groups of meteorological stations for the more humid area (north) and the semiarid/arid zone (center), reflecting the two distinct climatologies of the country, as identified in Figures 2.1 and 2.2. These data were then correlated with 3-month running means of the different teleconnection indexes. The operational definition of meteorological drought was taken as a period of five consecutive 3-month periods of negative SPI figures, reflecting the methodological approach used in other ENSO-related drought research (Chinh and Millington 2015). The resulting correlations for the negative phases are given in Figure 2.4 and for the positive phases of the indices in Figure 2.5 for the main growing season period. The analysis shows that the most important driver of Tunisian precipitation variability is the MO. When the MO index is positive (when there is a high-pressure system over the southwestern Mediterranean), precipitation in Tunisia decreases dramatically, especially during the autumn.

[16] The Oceanic Niño index (ONI) was used to capture the variations and phases in ENSO.

[17] NAOI was used to capture the variations and phases in NAO, the Mediterranean Oscillation index (MOI) was used to capture variations and phases in MO, and the Western Mediterranean Oscillation Index (WeMOI) used to capture variations and phases in WeMO.

FIGURE 2.4 Correlation between Years of Climatological Drought and the Negative Phases of ONI, NAOI, MOI, and WeMOI



Source: ICBA, 2017

Note: Correlation values for teleconnection indices > 0 with at least 80% confidence interval. Positive correlation, resulting in increased positive precipitation anomaly, is indicated in blue; negative correlation in red.

The correlations between the other teleconnection indexes and precipitation were weaker and more prominently negative. Because these are complex meteorological patterns and the indexes are generic pattern descriptors, it is not expected that they can fully explain the mesoscale and large-scale dynamics that affect the weather and drought in Tunisia or even in the western Mediterranean more generally. However, the analysis does suggest that the presence of high pressure in the western Mediterranean and Azores has more effect in blocking precipitation over Tunisia than does its absence in encouraging precipitation. Convection and orography may have a bigger role in directly enhancing precipitation compared with cyclonic circulation alone.

Recent observed events. The most recent climate-related developments in Tunisia and neighboring countries are presented in Annex 2.3, showing data on an annual basis for the last 10 calendar years through 2015 (2016 data were not yet available). Taking a broader view than simply referring to Tunisia was chosen to reflect the more general class of events that appear to have dominated the regional climate influenced by the vicinity of the Atlas Mountains and the Mediterranean Sea, both of which clearly affect Tunisia. This information is extracted from the annual *Bulletins of the American Meteorological Society* (Levinson and Lawrimore 2008; Peterson and Baringer 2009; Arndt, Baringer, and Johnson 2010; Blunden, Arndt, and Baringer, 2011; Blunden and Arndt 2012, 2013, 2014, 2015, 2016), which is the most comprehensive peer-reviewed global update on the state of the climate for any individual year. The reports have been made for a couple of decades, but only in the past decade or so has comprehensive attention been given to all populated regions of the world.[18]

2.4 IPCC PROJECTIONS FOR TUNISIA

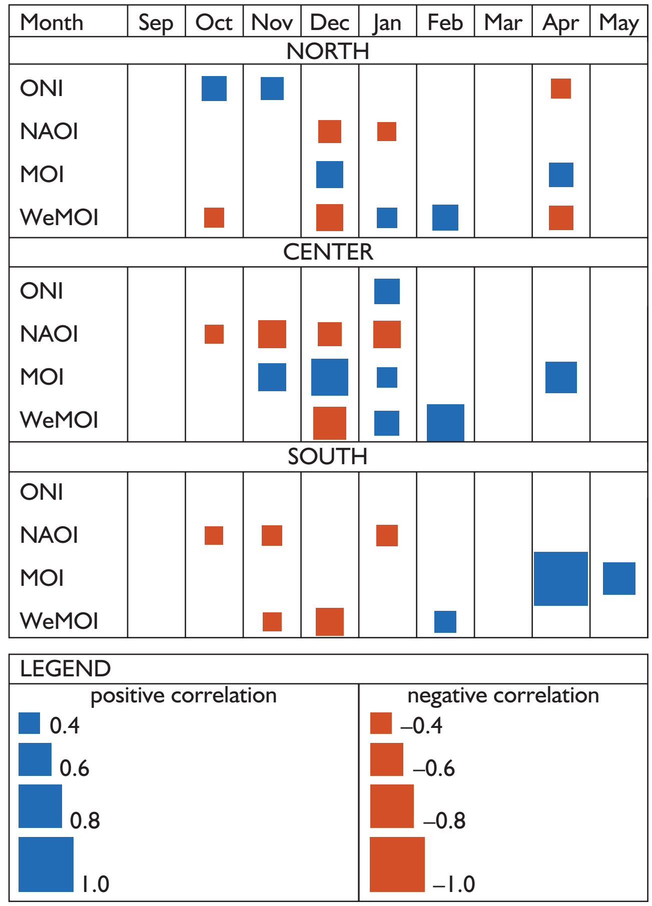
IPCC projections are expressed as anomalies with respect to the 1986–2005 reference period (that is differences between the future period and the reference period). Thus, the observed variations

[18] They also consider the fact that some parts of the world are not able to provide all the meteorological information collected within any given country, mostly because of internal conflicts and the remoteness of many meteorological stations as well commercial considerations by some meteorological services. Therefore, increasingly the reports utilize reanalysis products from major weather centers, such as the National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Forecasts (ECMWF).

are relative to the climate change that has occurred since the preindustrial period. The IPCC-type models are made available through the Coupled Model Intercomparison Project 5 (CMIP5; Taylor, Stouffer, and Meehl 2012) database. Following the same procedures used to produce the maps displayed in the IPCC report, the KNMI Climate Explorer was used to develop an on-line database to produce maps on a country-by-country scale. Because global climate models are by and large unable to represent details relevant to country scales such maps are at best indicative of things that may come. Figure 2.6 shows the annual mean end-of-century temperature changes for Tunisia for the RCP8.5 scenario,[19] whereas the annual mean relative precipitation change is depicted in Figure 2.7. In both cases, the figures represent the median values based on all available simulations.[20]

Figure 2.8 displays consistent model mean projected change for the end of century (2081–2100) versus 1986–2005 for the RCP8.5 scenario for the winter months October to April for precipitation, net water flux (precipitation minus evaporation), near-surface soil moisture, and near-surface atmospheric relative humidity. All of these components of the hydrological cycle clearly indicate that Tunisia and its neighboring countries are projected to experience substantially drier conditions with enhanced risks of droughts throughout the 21st century and in particular toward the end of this period and under high-end greenhouse gas (GHG) emission scenarios. With a strongly reduced hydrological cycle, runoff from the mountains and related water storage for the dry season (May through September) will also be influenced. In short, the water available for irrigation will be considerably less abundant than at present. Taking year-to-year variability into account also suggests that drought will occur relatively regularly in Tunisia in the future.

FIGURE 2.5 Correlation between Years of Climatological Drought and the Positive Phases of ONI, NAOI, MOI, and WeMOI



Source: ICBA, 2017

Note: Correlation values for teleconnection indices > 0 with at least 80% confidence interval. Positive correlation, resulting in increased positive precipitation anomaly, is indicated in blue; negative correlation in red.

Considered together, it is evident that, even for the next 20-year period (2017–2036), the general trend for Tunisia is for higher exposure to drought conditions. Equally important, the chances are high throughout the entire country, suggesting that widespread drought conditions may occur, thereby further challenging local small- and even large-scale agriculture. For the near term, the actual RCP scenario

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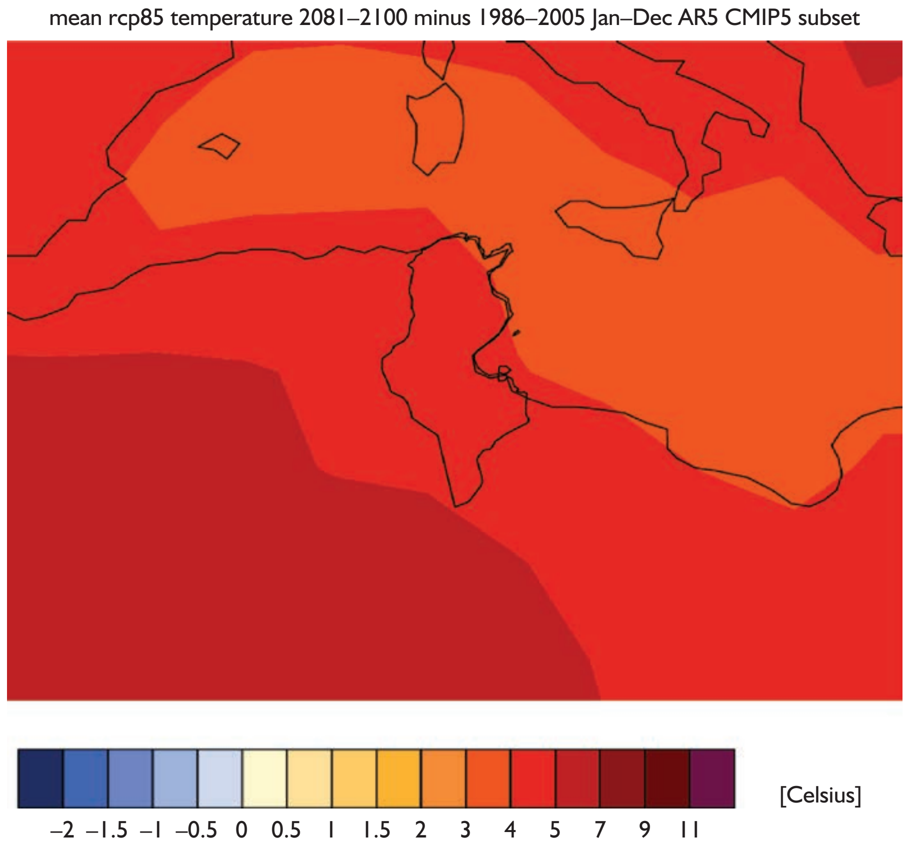
[19] IPCC (2013) maps for four different future representative concentration pathway (RCP; of greenhouse gas emissions) scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) have been elaborated. These scenarios represent increased forcing from the strongly mitigated scenario RCP2.6 (constructed to keep temperatures below 2.0°C) to a nonmitigated business-as-usual scenario RCP8.5. Only RCP8.5 is shown here. For each modeled grid point, the 25th, 50th, and 75th percentiles of the distribution of the CMIP5 ensemble are shown, as only the 50th percentile and the resulting climate change represents the years 2081–2100 versus 1986–2005. This includes both natural variability and intermodel spread.

[20] For a more complete sense of the projection uncertainties, the regional maps should be consulted.

FIGURE 2.6 Annual Mean Temperature Change (2081–2100) versus (1986–2005) as Projected for Tunisia by the CMIP5 Models for the RCP8.5 Scenario



Source: KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi).

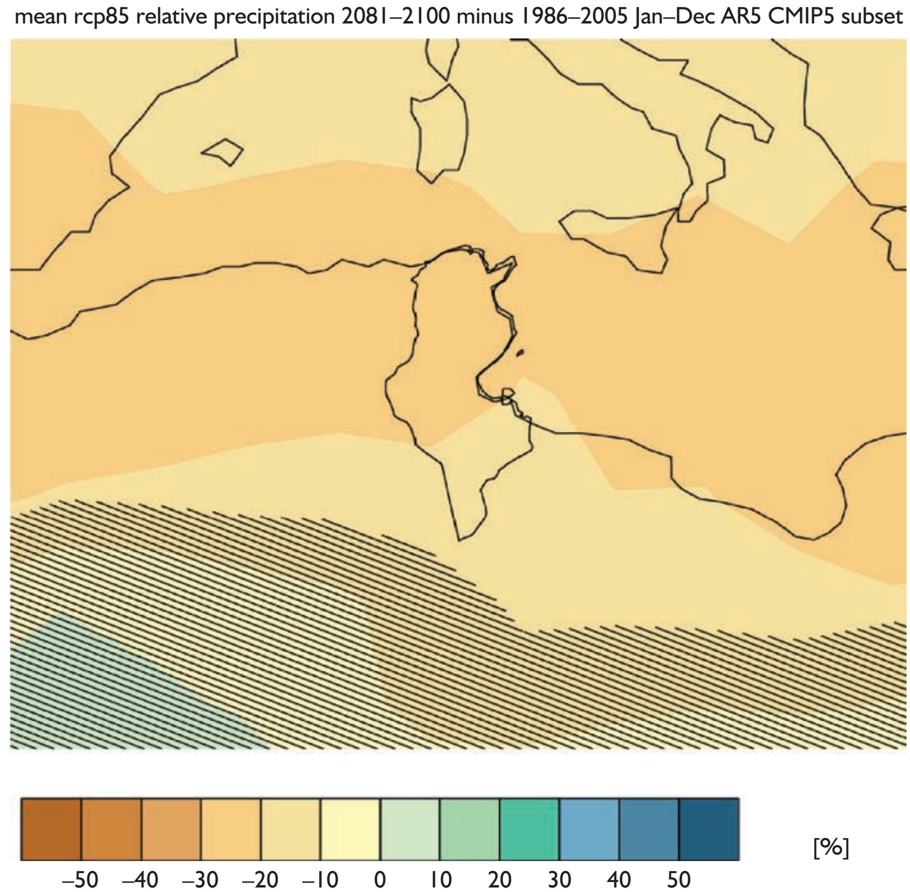
is not relevant because the climate system is basically still adjusting to the enhanced levels of GHGs already reached. But after the middle of the century, the scenarios start to differentiate among the RCPs.

Extreme events not related to droughts. Apart from droughts, the risk of flash floods and related hazards, such as hail storms and landslides, likewise could be considered. In general, it is to be expected that such events may occur throughout the year in the future. As is evident from Annex 2.3 on recent observed events, severe precipitation amounts during relatively short time periods already pose a challenge to Tunisia and its conditions for agriculture. Information from both on-the-ground observations and modeling shows that rainfall intensity may increase in some areas and seasons even as total rainfall decreases for the country as a whole. Thus, the same area may be subject both to drier conditions and more flooding. Annex 2.4 illustrates this on a global scale.

2.5 FUTURE DROUGHT PROSPECTS IN TUNISIA

Climate change is already affecting Tunisia at both the national and farm levels, according to stakeholder observations obtained by the International Center for Biosaline Agriculture (ICBA) and the University of Nebraska Lincoln (UNL) in 2016. From their anecdotal evidence, those interviewed

FIGURE 2.7 Annual Mean Relative Precipitation Change (2081–2100) versus (1986–2005) as Projected for Tunisia by the CMIP5 Models for the RCP8.5 Scenario[21]



Source: KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi).

suggest that a drying has occurred over the past 30 years with a movement north of more humid conditions, ensuring that the central part of the country is now more arid. For agriculture, changes in the water deficit, which is a critical variable, are likely to bring increased risk for several staple crops.

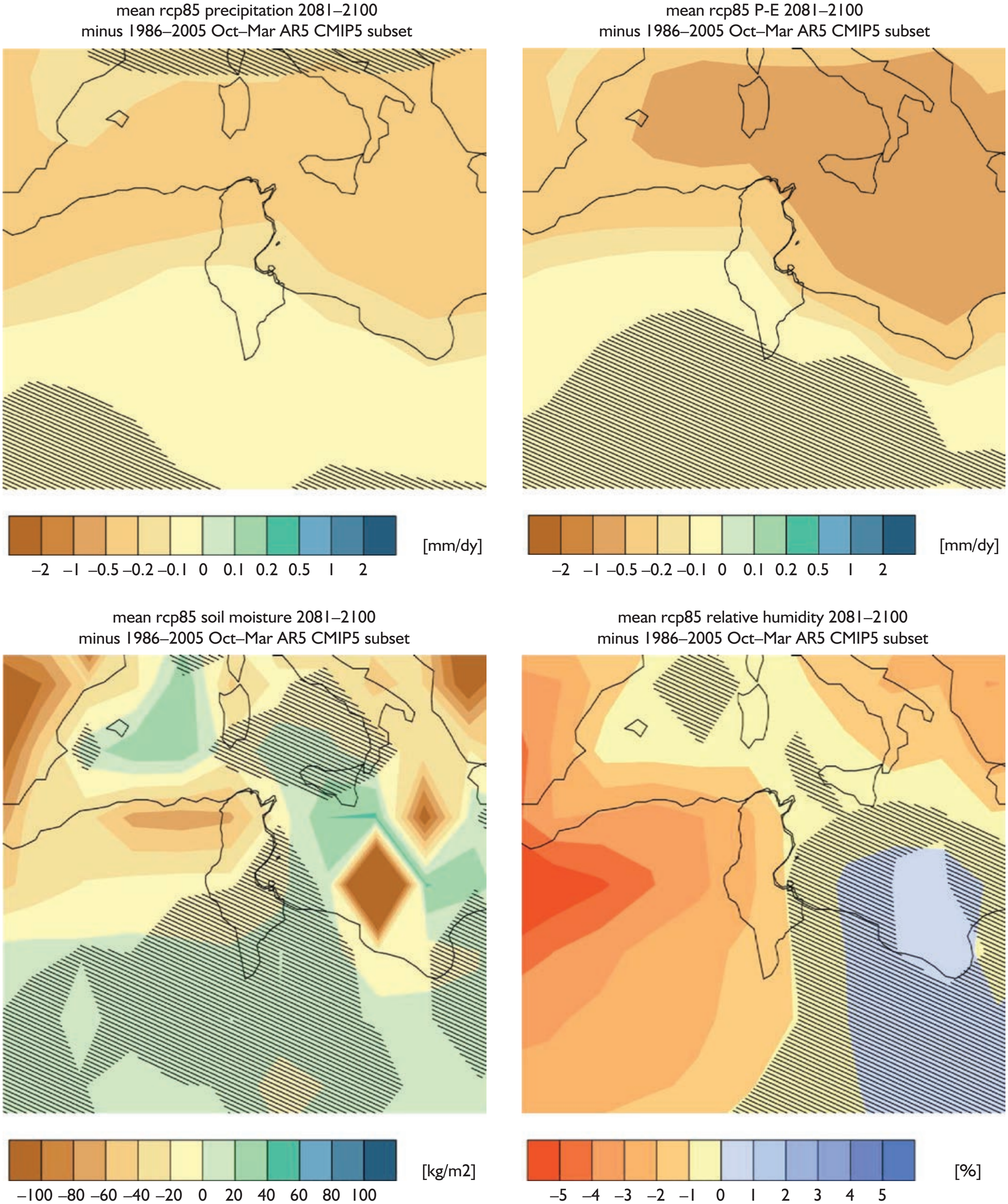
In recent climate change research for Tunisia, using statistical downscaling methods, Wilby (2013) showed that the annual mean maximum temperature for Tunis could rise by 1.5°C to 2.6°C, and annual precipitation could change between a 5 percent increase and a 20 percent decline. These findings are similar to more regional work for which climate models indicated mean temperatures would rise by 1.4°C to 2.5°C and precipitation would fall by 5 to 15 percent (Wilby, 2013).

To gain insight on future drought conditions in Tunisia, downscaled climate change data were downloaded from seven regional models made available through the Coordinated Regional Climate

[21] In addition to the observations related in the preceding footnote, the hatching in this figure denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences—a measure of robustness of the results. Hatching indicates that the change is not statistically significant, yet the sign and magnitude may still be relevant given the geographical pattern of the overall changes.

[22] See http://www.cordex.org/

FIGURE 2.8 Mean Projected Change for Winter (October–April)



Source: KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi).

Notes: *Upper left:* precipitation [mm/day]; *upper right:* net water flux (precipitation – evaporation) [mm/day]; *lower left:* near surface soil moisture [kg/m^2]; *lower right:* relative humidity [%]. 2081–2100 versus 1986–2005 as projected by the CMIP5 models for the RCP8.5 scenario.

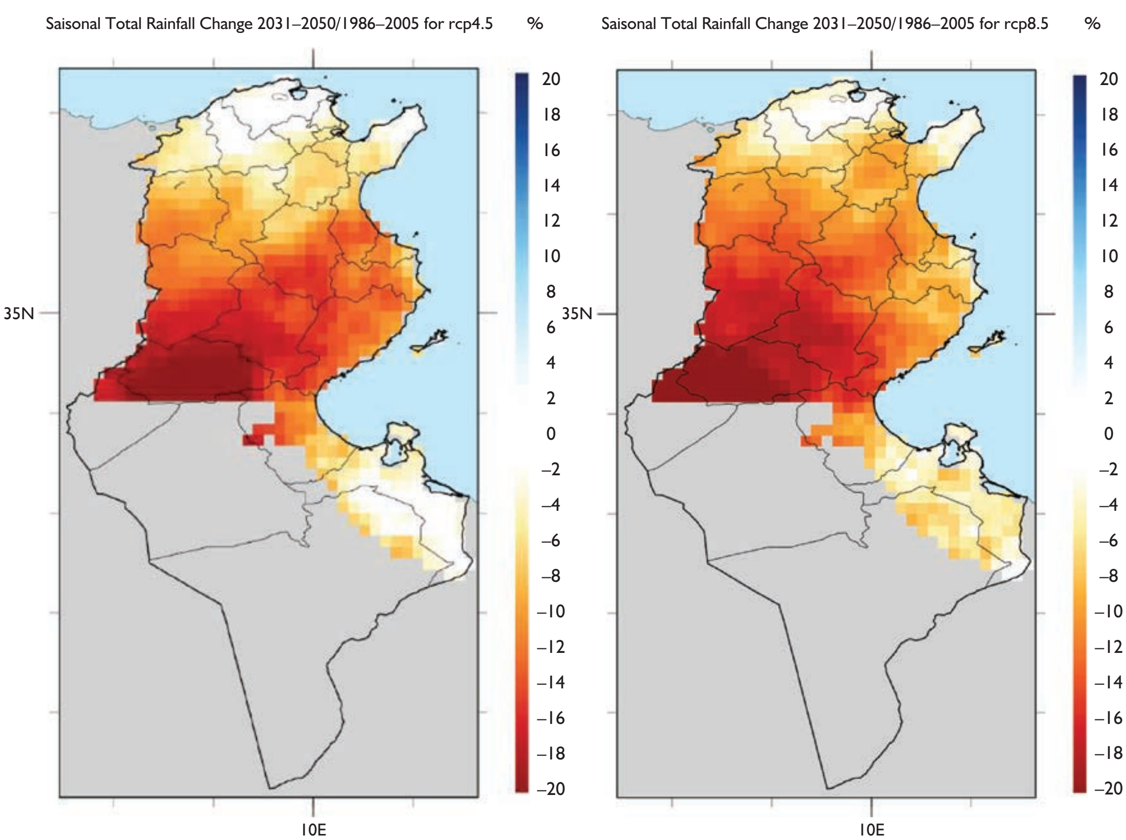
Downscaling Experiment (CORDEX)[22] project. Various outputs at different resolutions and different domains were available for the Tunisian area. For this study, the CORDEX-Europe domain was chosen at a resolution of 0.11 × 0.11 degrees to provide the most detailed insight in spatial terms. The seven models used are listed in Table 2.3.

To analyze the likely nature of future droughts, the decision rules for classifying years that are favorable and unfavorable for cereals production were used. In these rules, drought in Tunisia can be explained by the rainfall deficit over the cropping season of September to May in the north and central regions of the country. Using the amalgamated data from seven regional models and two GHG emissions scenarios (RCP4.5 and RCP8.5), projected total rainfall during the cropping season for the 2031–50 period was compared with historical data for 1986–2005 to characterize changes in precipitation patterns in the near future. The analysis focused on the humid and arid areas where there is currently some agriculture.

TABLE 2.3 CORDEX-EUR11 Regional Models Used

Modeling Center Name	Global Model	Regional Model
CNRM-CERFACS	CNRM-CM5	CCLM4-8-17
ICHEC	ICHEC-EC-EARTH	CCLM4-8-17
ICHEC	ICHEC-EC-EARTH	RACMO22E
IPSL	IPSL-CM5A-MR	WRF331F
MOHC	HadGEM2-ES	CCLM4-8-17
MOHC	HadGEM2-ES	RACMO22E
MPI	MPI-ESM-LR	CCLM4-8-17

FIGURE 2.9 Mean Change in Total Rainfall over the Cropping Season (September to May) Calculated as Difference between 2031–50 and 1986–2005



Source: Original data analysis from ICBA.

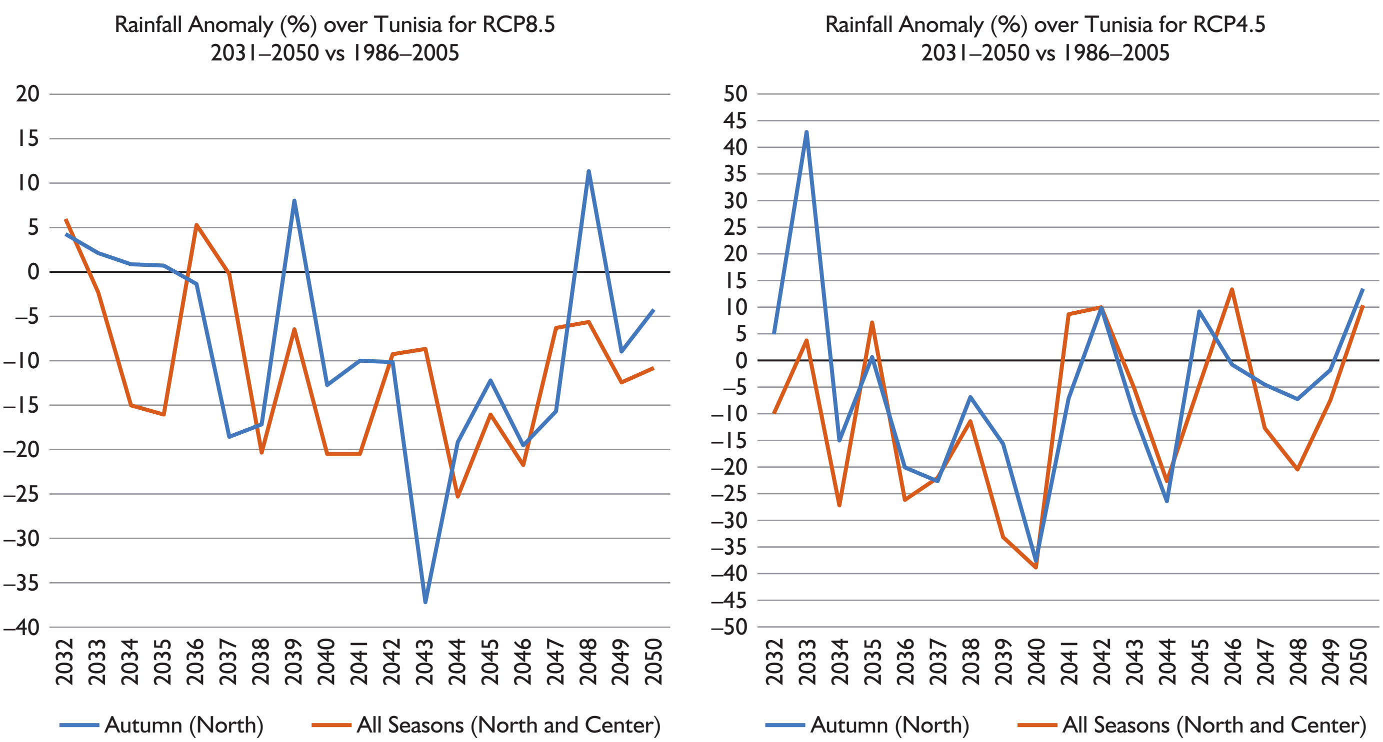
Notes: Seasonal means: (a) RCP 4.5 scenario and (b) RCP 8.5 scenario for the areas currently contributing to agricultural production. The gray areas within Tunisia are the Sahara Desert and are not included in the analyses because they are marginal to agricultural production.

The projections depicted in Figure 2.9 show the spatial variations in precipitation anomalies in northern and central Tunisia for the two RCP scenarios. It is apparent from this figure that, for the 2031–50 period, drier conditions during the cropping season will affect the central region more than the northern. This could mean that overall cereal production may not be severely affected because the most important production systems are located in the north.

Agricultural systems in the central region, such as the olive and almond intercropping with cereals and vegetables, are likely to be highly affected. At present, irrigation water is allocated primarily to grow cereals in the central region. However, as conditions become drier in the future, there will be conflicting positions as to whether it would be better to divert this water to irrigate olive and almond trees. Olives are a major contributor to Tunisian exports (51 percent of total agricultural exports in 2016). Almonds could also benefit from this irrigation water to limit imports and cover the increasing demand by the confectionery industry, which has grown steadily over the past decade.

There would also be impacts on high water-consuming cash crops, such as vegetables, which could be replaced gradually by almonds with a consequent investment in agri-food industry in areas close to the production basins. This would allow water savings and decrease illegal groundwater pumping, which is currently jeopardizing sustainability of the rural drinking water supply. This, in turn, could adversely affect the long-term well-being of the affected rural communities, perhaps leading to additional outmigration of the young. This is already a significant and worrisome trend in much of Tunisia, particularly in its less-advantaged regions, which are challenged by comparatively high youth unemployment rates.

FIGURE 2.10 Rainfall Anomaly for Northern and Central Tunisia over the Cropping Season (blue line) and for Northern Tunisia over Autumn (red line) for RCP8.5 and RCP4.5



Source: ICBA, 2017.

Finally, the temporal variability of likely future precipitation values was explored to gain further insight on changes in the likely frequency and duration of droughts. Using the same thresholds established earlier to characterize drought in Tunisia, the frequency of dry years was calculated for both the RCP4.5 and RCP 8.5 scenarios. Figure 2.10 shows the rainfall anomaly for northern and central Tunisia over the cropping season along with the rainfall anomaly for northern Tunisia in autumn. According to this analysis, the frequency of dry years in the country will increase to 52 percent (10 of 19 years) between 2031 and 2050 under the RCP4.5 scenario and to 79 percent (15 of 19 years) under the RCP8.5 one. Thus, drought in Tunisia is likely to be more frequent and severe in the future under both scenarios. As suggested, agricultural production in the central region of the country appears highly likely to be affected to a greater extent than that in the north.

2.6 IMPLICATIONS FOR AGRICULTURE

Agricultural practices around the world typically adapt to changing local climate conditions, although frequently with a lag. However, over the past decades, it increasingly has been realized that local climate conditions are often less stable than perceived by society. Not only does the climate vary on decadal time scales, resulting in quite variable year-to-year agricultural yields, but such variations also result in greater vulnerability to trends that have not been perceived because of a lack of long-term, quality-controlled observational data sets or inadequate response to existing information. Yet agricultural practices in many places appear to adjust if the information about changes is sufficiently robust. Thus, ensuring information robustness is a major requirement for effective corrective action.

Climate records of temperature and precipitation from the past century together with climate simulations for detection and attribution studies, as well as future projections, all show large variations on the regional scale. Therefore, all information about climate variability for small to moderate size countries, such as Tunisia, is at best indicative and cannot yet be used for predictions. In this context, the IPCC (2013c) distinguishes between climate *predictions* and *projections* as follows:

> ***Predictions:*** A climate prediction or forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, inter-annual, or decadal time scales. Because the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature.
>
> ***Projections:*** A climate projection is the simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the particular emission/concentration/radiative forcing scenario used, which, in turn, is based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not occur in practice.

However, this formally clear separation between predicted (with a certain likelihood estimate) future and projected story lines that may or may not be realized becomes blurred once the interest is to estimate agricultural yields in the near-term future. Instead of assessing vulnerability to plausible future scenarios,

the interest is often related to an actual prediction of regional and/or local climate conditions. This is one of the reasons studies addressing ENSO and other large-scale climate drivers have intensified in recent years. With some demonstrated seasonal to multiannual ability to predict the state of ENSO, there is a prospect that the predictability of droughts or chances for flash floods or large-scale flooding can be made with acceptable credibility. This also reveals why large international funding programs (for example the European Union's Horizon 2020) are directed toward these research needs.

This chapter has confirmed that there is an overall widespread annual mean warming (~2.5°C/century) trend for Tunisia. However, the country's complex terrain with mountains and a sharp climate gradient between the Mediterranean Sea and the more continental desertlike climate suggests that the local patterns of change may deviate from what can be extracted from the few meteorological stations considered here. The same can be said with respect to information about actual precipitation in any nongauged location. However, by viewing local developments in a broader regional context, it is evident that all known challenges to modern and traditional agriculture are already influencing the sector in Tunisia. Most severely among these is the occurrence of local and regional droughts or dry conditions, whose impacts on the agricultural sector are the focus of the next chapter. It is likewise clear that, with rising temperatures and the projected reduction in the net hydrological cycle, Tunisia increasingly will be challenged in terms of its water availability. Thus, both rain-fed and irrigated crops are already undergoing increasing pressure from a climate perspective.

Agricultural practices in Tunisia need to be better able to respond to both the short-term trends related to climate variability and the long-term ones associated with climate change. Furthermore, this needs to be based on the understanding that annual to decadal fluctuations will occur on top of the mean trend. Along with the temperature variation, there will be modulations to the hydrological cycle. Although no clear overall trend in precipitation is apparent from the records, it is nonetheless evident that rising temperatures enhance evaporation and that net water fluxes at the surface are shifting. Similarly, the availability of water for irrigation using mountain streams and reservoirs will continue to be stressed and at an increasing rate. Although drying is the long-term trend, the year-to-year variability will remain high. If predictive ability on seasonal over years to decadal time scales, as well as for MO and ENSO, can be improved, planning crop selections and the timing of crop planting can be enhanced. The mentioned large-scale efforts to improve long-term predictions are thus important for Tunisia to be fully cognizant of in the years ahead.

CHAPTER
THREE

CLIMATE CHANGE AND DROUGHT IMPACTS ON THE AGRICULTURAL SECTOR IN TUNISIA

This chapter examines in further detail the impact of increasing climate variability and more frequent and intense droughts on agricultural and livestock activities in Tunisia. It gives particular attention to the effects of drought on two important value chains, wheat and dairy products, which are critical for the country's agricultural export economy, as well as for the livelihoods of much of its rural population. It considers droughts' impacts on cereals production, which is vital both for domestic food security and production of animal fodder. Drought-related declines of cereals production often require increased imports of these goods and thus have an adverse influence on Tunisia's external trade balance and its overall macroeconomic performance, as well as on the social well-being of its rural communities.

3.1 THE AGRICULTURAL SECTOR: BASIC CHARACTERISTICS[23]

The agricultural sector in Tunisia plays an important role in terms of jobs, livelihoods, and the overall economy. Agriculture represents about 10 percent of GDP, with food processing accounting for around 10 to 12 percent of total exports. The sector also provides employment to almost all women in the countryside (World Bank 2014). The value of Tunisia's food production has increased by more than 50 percent during the past 15 years and now stands at over US$4 billion. An IFC report shows that investment in agriculture creates the largest amount of employment, whereas investment in food processing creates the greatest value added compared with the same amount of investment in other sectors (Kapstein, Kim, and Eggeling 2012).

Tunisia's scarce agricultural land area of 10.1 million ha employs almost 20 percent of the national labor force, approximately one third of which is composed of women. About 33 percent of the 11.1 million Tunisians live in rural areas, and roughly half depend on agriculture for their livelihoods and employment. In some lagging region governorates, close to 80 percent of the rural population depends on agriculture for its income and employment. In addition, many agricultural workers are situated near or below the

[23] This section is largely drawn from World Bank, *Tunisia Job Creation and Welfare Improvement through Agriculture,* Washington DC, 2017.

TABLE 3.1 Agricultural Land Use in Tunisia

Land Type	Million (ha)	Percent of Total
Arable land	5.0	50.0
Aboriculture	2.0	20.0
Field crops	2.0	20.0
Fallow	0.7	7.0
Other crops	0.3	3.0
Permanent ranqeland/pasture	4.0	40.0
Forest and woodlands	1.0	10.0
Total agricultural land	**10.0**	**100.0**

Source: Global Development Solutions 2017b.

poverty line (World Bank 2017).[24] In 2012, a third of the poor household heads in the country worked in agriculture compared with 16 percent of the nonpoor (Cuesta 2015).[25] Thus, the agricultural sector plays an essential role in the Tunisian economy, especially for the bottom 40 percent. Employment in agriculture can nonetheless provide a path out of poverty because the number of workers in agriculture is significant and still increasing (that is, at 0.2 percent per year between 2009 and 2014). Labor productivity in agriculture has also grown nearly three-fold since the 1960s.

Tunisia covers a total area of 163,610 km^2 (155,360 km^2 of land and 8,250 km^2 water) (International Trade Center), and the majority of the national territory (61 percent) is devoted to agriculture. Agricultural land area in Tunisia is estimated at 10 million ha (Table 3.1). Among these lands, as described by ONAGRI (2016), 2.8 million ha are in annual crops, 1.5 million ha in olives, 1.4 million ha in cereals, 2.3 million ha permanent crops, and 3.9 million ha in permanent pasture (http://www.onagri.nat.tn/). Among strategic crops, wheat is the one most cultivated in the Mediterranean basin (Elias and Manthey 2005) and constitutes the main component of the Tunisian diet in the form of pasta, couscous, and bulgur, with consumption reaching 258 kg per year per capita (Chahed 2009). The north and central regions of the country focus primarily on cereal cultivation, whereas the drier parts of the center and the even more arid south utilize land predominantly for grazing.

Key crops and livestock products in Tunisia include olives, cow milk, chicken meat, dates, and wheat, which collectively represented 52 percent of agriculture production value and one-third of production quantity in 2013 (the most recent year for which such data are available). As Table 3.2 indicates, whole fresh cow milk contributed 13 percent of total agriculture production value, whereas wheat (both durum and soft) contributed 7 percent. The data highlighted in Tables 3.2–3.4 refer to the key value chains that are the focus of the third section of this chapter: wheat and dairy products.

Virgin olive oil and dates provided nearly half (49 percent) of Tunisia's agricultural product export value in 2013. Macaroni, a durum wheat product, contributed 4.4 percent (US$66.0 million). Processed cheese also ranked high among exported agricultural products (2.3 percent or US$34.4 million).

Despite the significant production of wheat for domestic consumption, wheat also leads Tunisian imports (20 percent in terms of value). Other significant imports include soybeans, barley, and maize, which are used in part for dairy cattle and other livestock feed (see Table 3.4). Together with wheat, they tend to increase significantly as a share of total imports during drought compared with nondrought years.

Historically, the agriculture sector has been dominated by small family farms growing subsistence crops with little market integration, but though the number of larger agricultural enterprises has expanded in recent decades. In 2005, there were an estimated 516,000 farms nationally (APIA, http://www.apia.com.tn/lagriculture-tunisienne-investmenu-85). Although the average farm size in Tunisia is 10.2 ha,

[24] According to FAO data, about 80 percent of Tunisian farms are smaller than 20 ha in area, and more than 50 percent are smaller than 5 ha.

[25] Analyses in Cuesta (2015) shows that nonpoor workers are half as likely to work in agriculture as the working poor, and agriculture is the largest employment sector, employing on average 40% of individuals across cohorts.

TABLE 3.2 Most Important Crops and Primary Livestock Products in Tunisia Ranked by Highest Gross Production Value, 2013

Item	Value (US$, millions)	Percent of Total	Quantity (MT)	Percent of Total	Production Unit Value (US$/MT)
1 Olives	569.1	14.9	1,100,000	11.8	517.3
2 Milk, whole fresh cow	488.9	12.8	1,149,000	12.3	425.5
3 Meat, chicken	374.4	9.8	140,000	1.5	2,674.1
4 Dates	307.4	8.1	195,000	2.1	1,576.6
5 Wheat	258.3	6.8	975,490	10.4	264.8
6 Eggs, hen, in shell	199.0	5.2	98,500	1.1	2,020.1
7 Tomatoes	177.4	4.6	1,079,000	11.6	164.4
8 Almonds, with shell	121.7	3.2	52,000	0.6	2,340.3
9 Chilies and peppers, green	118.6	3.1	384,000	4.1	308.7
10 Potatoes	109.1	2.9	385,000	4.1	283.3
Other	1,092.1	28.6	3,781,294	40.5	288.8
Total	**3,815.8**	**100.0**	**9,339,284**	**100.0**	**408.6**

Source: Global Development Solutions 2017b analysis of FAOSTAT data.
Note: FAO-assigned value for 81 percent of crop/primary livestock production.

TABLE 3.3 Agricultural Exports from Tunisia Ranked by Value, 2013

Item	Export Value (US$, thousands)	Percent of Total	Export Quantity (MT)	Percent of Total	Export Unit Value (US$/MT)
1 Oil, olive, virgin	504,581	33.7	151,035	19.0	3,340.8
2 Dates	233,962	15.6	105,803	13.3	2,211.3
3 Macaroni	66,034	4.4	89,004	11.2	741.9
4 Oil, maize	58,489	3.9	34,522	4.3	1,694.3
5 Margarine, short	46,146	3.1	26,110	3.3	1,767.4
6 Pastry	44,608	3.0	18,680	2.3	2,388.0
7 Food prep nes	37,664	2.5	20,542	2.6	1,833.5
8 Chocolate products nes	35,673	2.4	10,879	1.4	3,279.1
9 Cheese, processed	34,444	2.3	10,815	1.4	3,184.8
10 Beverages, nonalcoholic	32,582	2.2	51,705	6.5	630.2
Other	402,843	26.9	277,033	34.8	1,454.1
Total	**1,497,026**	**100.0**	**796,128**	**100.0**	**1,880.4**

Source: Global Development Solutions 2017b analysis of FAOSTAT data.

TABLE 3.4 Agricultural Imports by Tunisia Ranked by Value, 2013

Item	Import Value (US$, thousands)	Percent of Total	Import Quantity (MT)	Percent of Total	Import Unit Value (US$/MT)
1 Wheat	509,202	20.0	1,485,639	30.9	342.7
2 Soybeans	287,070	11.3	467,490	9.7	614.1
3 Barley	241,455	9.5	821,325	17.1	294.0
4 Maize	234,775	9.2	867,519	18.0	270.6
5 Oil, soybean	129,782	5.1	120,046	2.5	1,081.1
6 Sugar refined	125,479	4.9	224,742	4.7	558.3
7 Cigarettes	79,894	3.1	3,332	0.1	23,977.8
8 Oil, palm	69,157	2.7	75,989	1.6	910.1
9 Oil, maize	68,822	2.7	57,177	1.2	1,203.7
10 Sugar raw centrifugal	61,125	2.4	139,005	2.9	439.7
Other	736,337	29.0	549,117	11.4	1,340.9
Total	**2,543,098**	**100.0**	**4,811,381**	**100.0**	**528.6**

Source: Global Development Solutions 2017b analysis of FAOSTAT data.

TABLE 3.5 Water Resources in Tunisia, 2008[26]

Water Source	Billion m^3		Percent Mobilized	Origin
	Available Water	Mobilized Water		
Surface water	2.7	2.1	78	29 larqe dams; 222 small/medium dams, 810 hilly lakes
Ground water	2.1	2.0	95	4700 deep wells; 138,000 shallow wells
Total	**4.8**	**4.1**	**85**	

Source: APIA 2017.

just over half (54 percent) of all farms are smaller than 5 ha (Ghanem 2015) and 75 percent are smaller than 10 ha (APIA 2017). The majority of Tunisian farmers grow basic rain-fed grain crops (wheat and barley), and, as will be shown in greater detail in the next section, their output varies significantly in response to the highly variable rainfall conditions. Livestock and irrigated horticulture crops are also well developed but must frequently be supplemented by imports to ensure sufficient domestic supply. Tree crops (olives, citrus, and dates) are mostly export-driven.

Only 7 percent of agricultural land is irrigated (Chahed et al. as cited in FAO 2009), and this total did not exceed 400,000 ha in 2016 (http://www.onagri.nat.tn/). Thus, Tunisian agriculture remains highly vulnerable to recurrent droughts. Water resources utilized for both drinking water and irrigation include 4.8 million m^3 of surface water and groundwater, of which 85 percent is mobilized (see Table 3.5).

[26] The source did not indicate river water, size of dams, or depth of wells.

Despite some advances in recent years, such as those seen in growth of the olive sector, Tunisian agriculture has not yet reached its full production and export potential and thus can further contribute to boosting shared prosperity. However, current agricultural policies undercut employment and economic growth to a significant extent, in the process intensifying existing disparities between leading and lagging regions. Agriculture policy focuses mainly on self-sufficiency of cereal production to ensure food security (World Bank 2014), so considerable room remains to take advantage of high-value crops that are both labor-intensive and in high demand.[27] In addition, Tunisia has market access that has still not been fully exploited, including quotas allocated by the European Union (EU). More specifically, it has access to EU reduced-tariff or duty-free quotas for olive oil, 60 percent for citrus, and 70 percent for tomatoes. Tunisia has used only about 20 percent of these allocations in recent years (World Bank 2017). The African, Russian, and even East Asian markets also provide significant export potential. Morocco is already tapping into the two former markets.

According to some analysis (World Bank 2014), benefits of Tunisia's agricultural policies presently accrue primarily to large landowners who produce beef, milk, and wheat. As a result, these policies provide limited benefits to smallholders and cause consumers to pay higher prices. Thus, current policies could be reoriented to focus more on reducing regional disparities and supporting crops that would improve income and livelihoods for the majority of farmers (those who have small farms). Among the potential benefiting subsectors are arboriculture and vegetables produced in greenhouses, and there is considerable scope to include smallholder farmers in value chains as well as to capture new markets to increase jobs and incomes.

As suggested previously and shown in greater detail later, the impacts of droughts on agriculture in Tunisia have been devastating in the past because most of the rural poor live in economically lagging regions where agriculture has been the most important sector for employment and livelihoods. The total number of farmers is around 600,000 (including 17 percent in fisheries and 6 percent in related agri-food industries), but this figure is decreasing annually as the consequence of various social and economic factors. Low professional status, poor training opportunities, land fragmentation from inheritance, and limited access to credit for smallholders have all contributed to an inability to diversify production systems and accrue the capital needed for modernization, inducing an outflow of younger people and also limiting farmer resilience to drought impacts.

3.2 DROUGHT IMPACTS ON THE AGRICULTURE AND LIVESTOCK SECTOR

Interyear climate variability has long been a part of southern Mediterranean environments, with 29 significant droughts and 13 floods between 707 and 1900 CE identified in historical records of various forms. A major drought occurred in 1897, for example, and its consequences were made worse for Tunisia's citizens because of a simultaneous strong sirocco and locust plague. Since then, more than 31 recorded droughts have resulted in famines as rain-fed cereals, the main staple crop in the country, have been affected severely.

[27] To maintain food affordability, the government provides significant food subsidies, representing 1.4 percent of GDP, for a number of imported and domestic products.

Droughts have also played a part in social and political change. The famine conditions that resulted from the 1926–27 and 1931–33 droughts were exacerbated by the large exports of durum wheat to France at the time, which led to great discontent among the Tunisian population. A few years later, the drought of 1937–38 led to a rural revolution, and the first major rural exodus occurred because of the drought of 1946–47 (Hénia 2003). After Tunisian independence in 1956, droughts continued to plague many farming areas in the nation and contributed to the second major rural exodus between 1960 and 1965. Resilience within the communities was through traditional water savings infrastructure, such as in Tabias, Jessours, Meskats, Mgouds, Mejetls, on-farm food production diversification, and transhumance for herders.

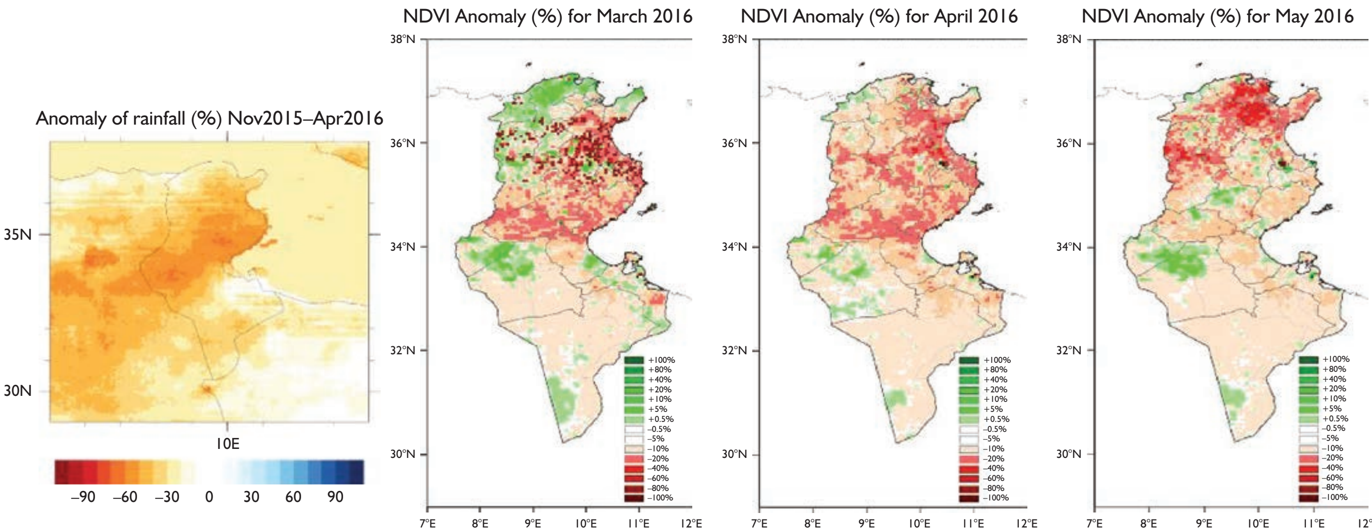
During the most recent (2015–16) drought, rain-fed agriculture and water supplies were particularly affected. At some of the key dams used for drinking water supplies, the reservoir storage deficit reached just 41 percent of normal conditions, leading to multiple disruptions. Watchwater Tunisia, a local nongovernment organization (NGO), recorded 851 water cuts without previous alert from the water utility Société Nationale d'Exploitation et de Distribution des Eaux (SONEDE); the cuts were spread across much of the country. Even in urban areas, drinking water supplies were affected. Cities such as Sfax, Sousse, and Nabeul and some localities in the Greater Tunis region experienced nighttime disruptions, particularly in July 2016. Discontent among some people was high, and demonstrations took place in remote rural areas. In response to the impacts on water resources, decrees passed focused on managing water supplies more effectively by undertaking maintenance or the construction of new dams (Decrees 2016-1271, 2016-1272, 2016-1273). The Tunisian government's drought response measures are discussed in greater detail in the next chapter.

In the recent drought, rainfall in many parts of central Tunisia was more than 40 percent below normal levels from November 2015 through April 2016 (Figure 3.1a). Former Minister S. Seddik warned in an interview with *Le Figaro* on August 17, 2016, that the drought would continue to be even more catastrophic if summer breaking rains were weak and the autumn season was dry. Unfortunately, the dryness continued into the next growing season, with a rainfall deficit of over 60 percent by October 2016. Relief came in November and December with heavy rains, which were 45 percent above average, but even afterward dam storage did not exceed 650,000 mm^3, which is only 65 percent of the average level, at the end of the year (ONAGRI, 2017).

The resulting vegetative stress in cropland areas, shown clearly in satellite-derived imagery and the images for the spring of 2016, indicates the increases in severity of the drought and its spread north into the humid zone (Figures 3.1, b, c, and d). The unnatural dryness in the late autumn of 2015 and the lack of winter rains resulted in vegetation stress during the spring of 2016, which were critical times for crop development and growth for rain-fed staple crops, such as wheat and barley.

Figures from the Tunisian Farmers Union (UTAP) estimated drought damage at 800 million dinars in total with 50 percent on farm (Micheletti, 2016). Consequences for farmers included crop failure (200,000 ha for grain cereals and 85,000 ha for cereal fodders and legume fodders), serious crop yield decline (0.5 million tons less than average values for the last 33 years), and 100 percent inflation in the market for hay, forcing farmers to sell their female sheep at 50 percent of the normal price. It was estimated that small ruminant herds would decline by 20 percent. Olive production declined 28 percent, and only 690 olive oil millers of 1,700 functioned in 2016. Other recorded consequences included a restriction in the area growing tomatoes (5,000 ha) because of a disruption in irrigation waters coming from dams. In a few locations, animal immolation occurred because of extreme thirst. The picture was

FIGURE 3.1 (a) Rainfall Anomaly Data for Tunisia for November 2015–April 2016 Showing the Areas Most Affected by Drought. (b) Normalized Difference Vegetation Index (NDVI) Anomaly Data for March 2016 Showing Parts of the North and Center, Particularly to the East, Experiencing Stress. (c) NDVI Anomaly Data Showing the Spread of Vegetation Stress Conditions in April 2016 to Most Parts of the North. (d) NDVI Anomaly Data Showing the Areas Still Experiencing Severe Vegetation Stress.



Source: ICBA, 2017.

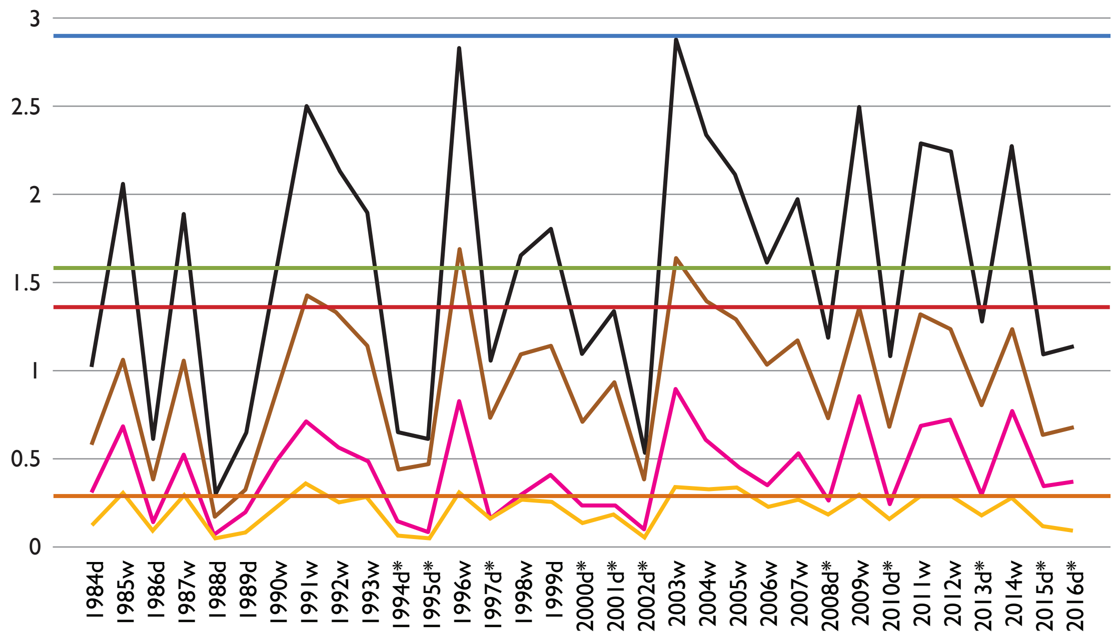
not all grim, however, and with the exception of winter vegetables that were affected by heat during winter season, all other irrigated crops, such as vegetables and citrus, were not affected. Citrus production was 60 percent above average because of a lower incidence of disease as a result of the dry conditions. Irrigated crops were harmed only if a second consecutive dry year occurred, and as a consequence, water salinization increased.

One of the most important drought impacts is on cereals, which make up an important component of the Tunisian diet. Thus, any drought-induced decrease in supply requires increased imports to fill the gaps. With most production being rain-fed, the effects of low precipitation on yields, as shown in Figure 3.2, are clearly understandable. Because average annual output is around 1.5 million tons, deviation from this level will define a year as a productive one for a positive anomaly and a deficient one for a below-average value for a dry year. The total cereals (shown by the black line in Figure 3.2) is highly variable around the green line (average production) with wet and dry years in almost equal measure and drought years clearly identified by the marked decline in yields.

The impacts of the droughts in 1994–95 and 2000–02 were significant, with the government spending more than US$4 million to stabilize bread prices. In the most recent such event, the drought caused a deficit in the food trade balance of roughly 950 million dinars in mid-2016, which was in sharp contrast to the positive food balance (+90 million dinars) in 2015. In 2016, the cereals bill was about US$675 million because of the need to import 3.3 million tons at global prices, which luckily were 10 to 25 percent lower than they had been in 2015. The government blamed the extension services for the hardship caused, and many closed after this event.

There has been little comprehensive research on drought in Tunisia, so limited insight is provided by previous studies. One area of focus has been the long-term reconstruction of past events using tree-ring

FIGURE 3.2 Cereal Production in Million Tons: Total Cereals (*black line*), Durum Wheat (*yellow line*), Barley (*magenta line*), and Bread Wheat (*brown line*). Maximum Production (*blue line*), Average Production (*green line*), Threshold of Government Declaration of Drought (*red line*), and Minimum Production (*orange line*). Dry and Wet Years Denoted by d and w, respectively; *Official Drought Declarations



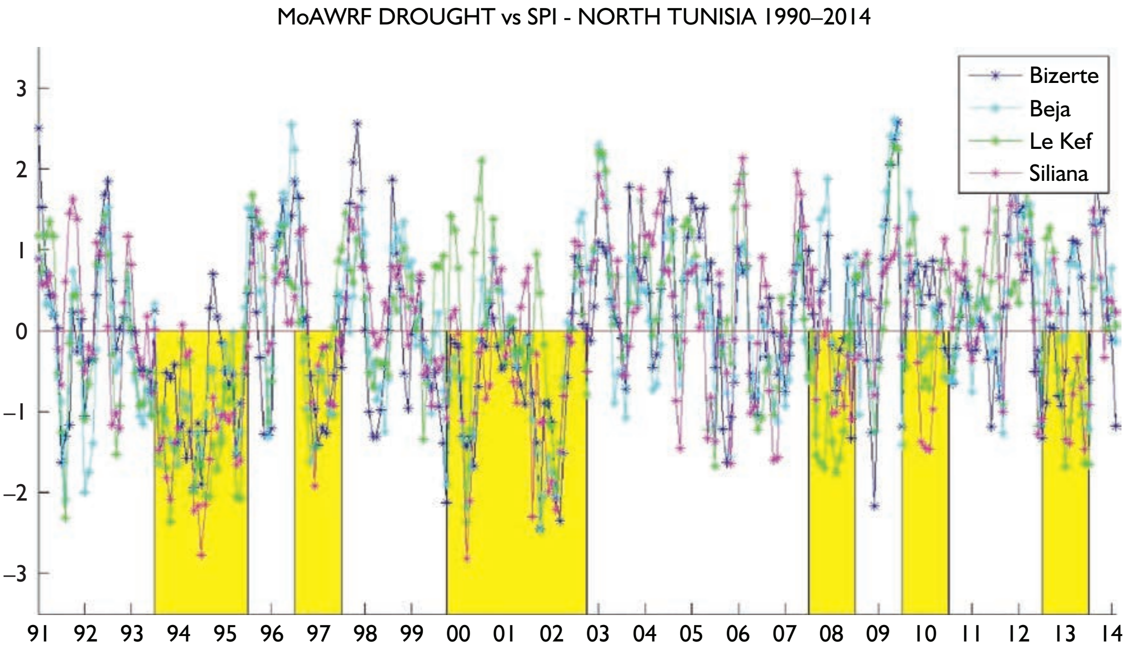
Source: ICBA, 2017.

data that helps to establish today's climate context (Touchan et al. 2008, 2011; Cook et al. 2016). The analysis highlighted the occurrence of large-scale regional droughts before the 16th century and more mixed patterns to these events in subsequent centuries. Most importantly, the data reveal a shift toward drier conditions across northwest Africa in the most recent decades.

In other studies, the focus has been on experimentation, testing the drought tolerance of various cropping species and genotypes. Ghrab, Gargouri, and Ben Mimoun (2008), for example, investigated almond and pistachio trees under limited water supply conditions. They found that almond cultivars were particularly affected by cyclic severe drought. For cereals, Forster et al. (2004) examined physiological and genetic traits for a wide range of barley germplasm for drought tolerance. Thameur, Lachiheb, and Ferchichi (2012) studied the effects of drought on the growth and yields of two local strains of barley. Similar studies for wheat have shown the impact of interannual rainfall variability on yields (Latiri et al. 2010).

To examine the patterns and timing of drought in Tunisia from 1991 to present, meteorological data from 24 stations were analyzed and SPI values generated for key areas in the north, northwest, and center-west of the country (Figures 3.3, 3.4, and 3.5, respectively). The resulting graphs highlight the inherent variability of the precipitation in these areas, with wide swings in SPI between wet and dry years, particularly in the north and northwest.

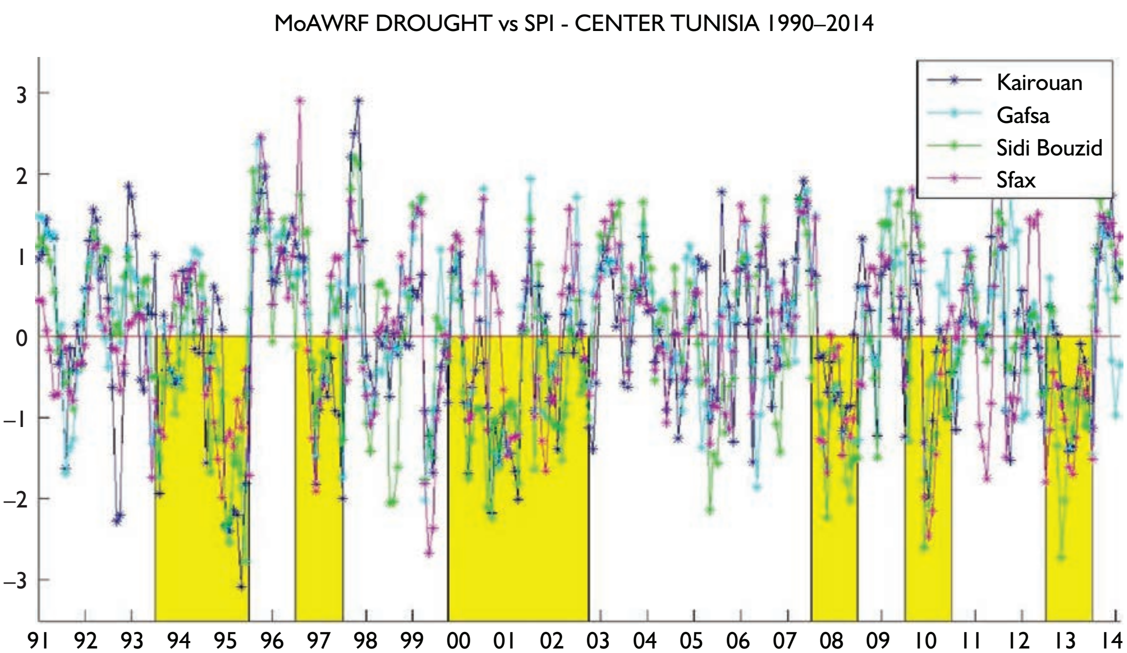
FIGURE 3.3 Values at Four Northern Tunisian Meteorological Stations (Bizerte, Beja, Le Kef, and Siliana)



Source: Original data analysis from ICBA.

Note: Agricultural drought years according to Tunisian government are highlighted in yellow.

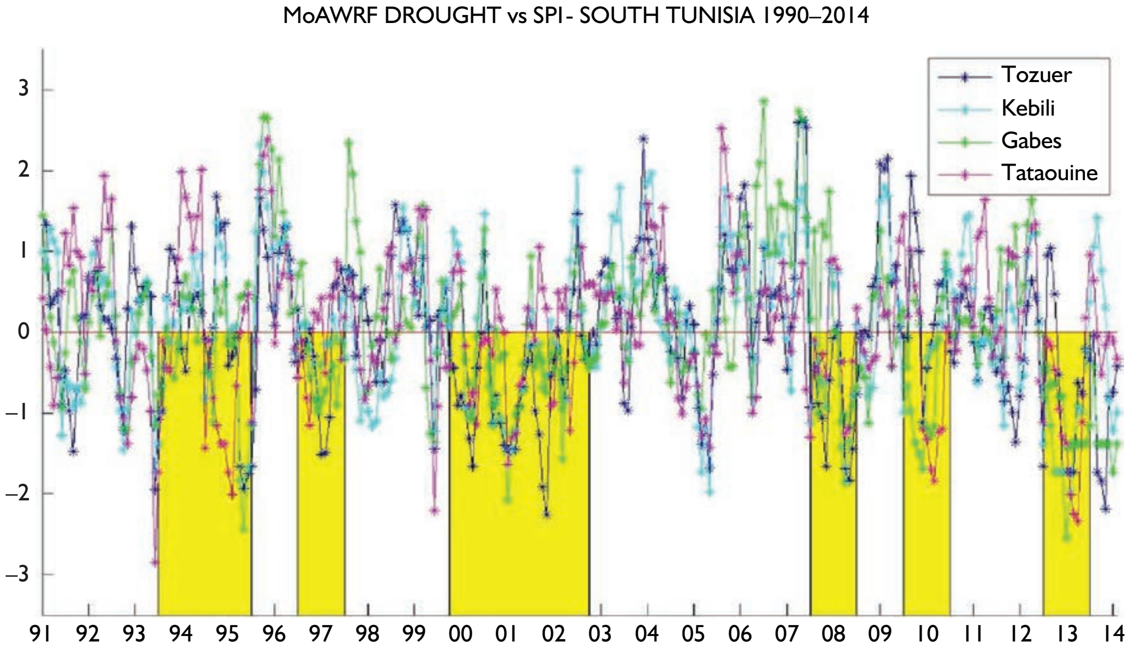
FIGURE 3.4 SPI Values at Four Central Tunisian Meteorological Stations (Kairouan, Gafsa, Sidi Bouzid, and Sfax)



Source: Original data analysis from ICBA.

Note: Agricultural drought years according to Tunisian government are highlighted in yellow.

FIGURE 3.5 SPI Values at Three Central-eastern Tunisian Meteorological Stations (Tozeur, Kebili, Gabes, and Tataouine)



Source: Original data analysis from ICBA.

Note: Agricultural drought years according to Tunisian government are highlighted in yellow.

3.3 SECTORAL IMPACTS OF SPATIAL–TEMPORAL VARIABILITY OF DROUGHTS IN TUNISIA

To understand more of the spatial–temporal variability of droughts and their impacts on agricultural areas in Tunisia, various gridded meteorological data sets were analyzed and linked to the crop data. With limits on the available ground station data, such as length and breaks in the record, availability, and poor spatial coverage, available gridded global data sets were used to explore the Tunisian droughts in more detail. Two main climatological zones were used as the basis of the analysis: north + central zone = zone 1 (covering all the cereal areas in Tunisia), and north zone = zone 2 (with more than 80 percent of cereals) (see Figure 3.1b for north and central regions). These were selected because of their importance for agriculture. Two periods were defined to reflect the importance of timing on drought impacts: autumn (September 1 to November 30) and the 9-month growing season (September 1 to May 31). The south of the country was excluded because it is less significant for agricultural production and for the summer period because drought has significantly less effect because crops have already reached maturity.

Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS)[28] daily data (Funk et al. 2015), which starts in 1981, and E-OBS[29] and CRU[30] figures were validated for the two seasonal periods against 15 years of ground station data from the National Meteorological Institute (INM) (see Figures 3.6 and 3.7).

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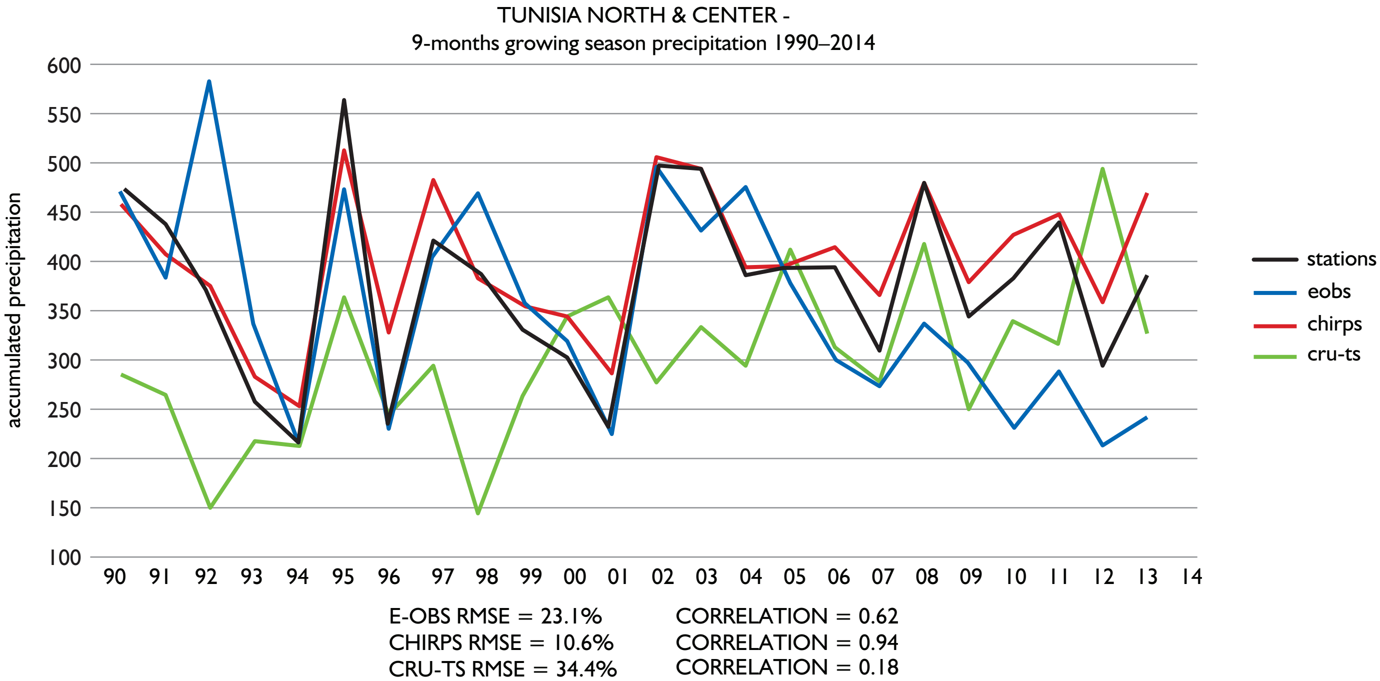
[28] CHIRPS data generated at the University of California Santa Barbara.

[29] The ENSEMBLES daily gridded observational data set for precipitation, temperature, and sea level pressure in Europe is called E-OBS. (https://www.ecad.eu/)

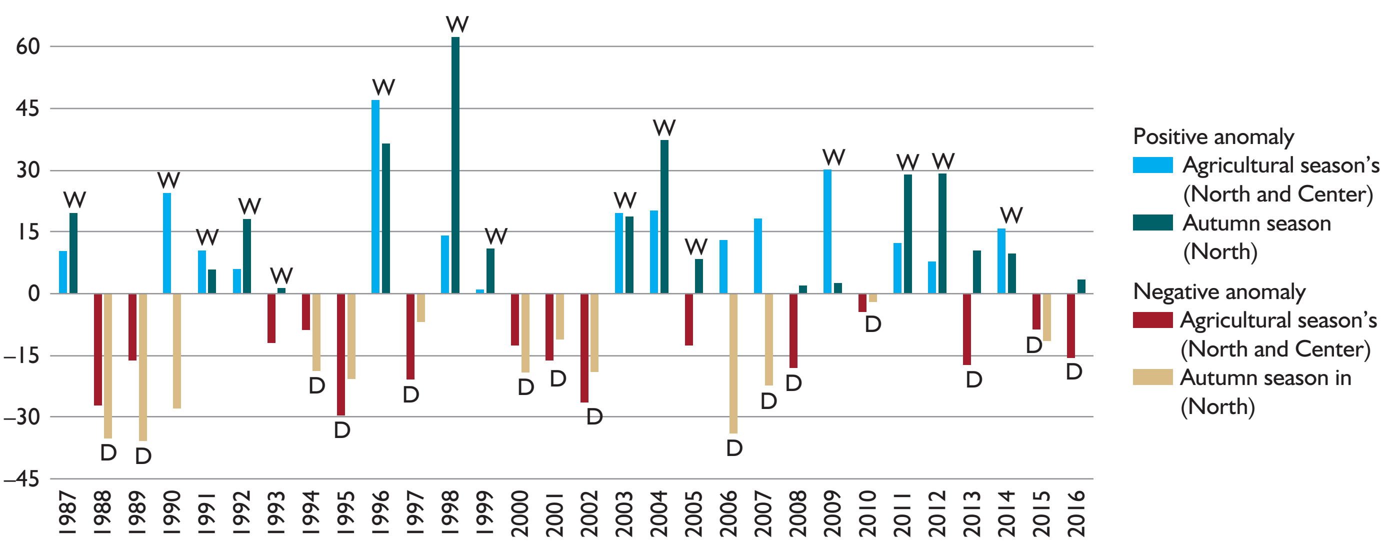
[30] CRU data generated at the University of East Anglia.

FIGURE 3.6 Comparison of Three Monthly Cumulative Precipitation for the CHIRPS (*red line*) Performance in the Northern and Central Zones for the Nine-month Season Precipitation Compared with Station (*black line*), CRU (*green line*), and E-OBS Data (*red line*)



Source: ICBA, 2017.

FIGURE 3.7 Percentage Anomalies in Precipitation for the Autumn and Agricultural Seasons and for the North and Northcentral Regions of Tunisia



Source: ICBA, 2017 .

The comparison shows that the four data sets identified many of the drought events but that the CHIRPS data were more closely aligned with the observed values for seasonal precipitation with a 3-month root mean square error of 10 mm (less than 8 percent). This data set was then used as the basis for further analysis to define spatiotemporal relations linking dry years to the precipitation budget and patterns.

For each subregion, the anomalies of precipitations were calculated in percentage terms so that periods of below- and above-normal values for the two defined parts of the growing season could be identified. This allows a comparison of the timing and extent of the precipitation anomalies with the known crop yields to begin to understand their impacts on agriculture. A simple decision tree algorithm, which combined knowledge on crop growing season dynamics with precipitation values, was developed to easily characterize the dry and wet year, having the following characteristics:

a) If the rainfall anomaly of the growing season (from September 1 to May 31) in Zone 1 is positive, the year is automatically productive and wet.
b) If the rainfall anomaly of the entire growing season in Zone 1 is negative (lower than –15 percent) and the anomaly of the autumn season (September 1 to November 30) in Zone 2 is positive, the year is productive and wet.
c) If the rainfall anomaly of the entire growing season in Zone 1 is negative (lower than –15 percent) and the anomaly of the autumn season in Zone 2 is negative, the year is considered dry with less than intermediate production.
d) If the rainfall anomaly of the entire growing season in Zone 1 is negative (lower than –15 percent), the year is considered dry.

The resulting values were compared with government cereal production data for the same period that would indicate the occurrence of drought. The 13 droughts identified from the CHIRPS anomaly data were highly correlated with the events shown in the cereals yield data using the four decision rules, so there is confidence in the definition and assessment of the climatology.

Figure 3.7 highlights the natural variability of the rainfall in both wet and dry years across the north and north and central regions of Tunisia. During the period analyzed there were 12 favorable years for cereal production (see Figure 3.2), which were characterized by positive precipitation anomalies for both the autumn and the entire agricultural season. The wettest years for both autumn and the entire seasons were 1987, 1991, 1992, 1996, 1998, 2003, 2004, 2011, and 2012, with the wettest among these occurring in the mid-1990s, when precipitation was more than 45 percent above the average rainfall. In recent decades, wet years are characterized with around 30 percent above-average rainfall conditions, but cereal yields have remained on a par with wetter conditions as a result of improvements in production practices. These have included increased subsidies from the government for fertilizers and pesticides, a greater transfer of research findings into practices on the ground, and the restructuring of the agricultural extension services, which are now centered at the Ministry of Agriculture's National Institute for Field Crops" (INGC) and its satellite offices.

More unfavorable years are characterized by negative precipitation anomalies throughout the growing season. These years, 1988, 1989, 1994, 1995, 1997, 2000–02, 2010, and 2015, were officially declared as drought years by the government, with the exception of 2015, and there are noticeable declines in cereal yields. Although there has been no noticeable increase in frequency of droughts, those in 2000–02 were particularly severe either because of their duration or their intensity.

For years with more variable precipitation anomaly patterns, it was found that, with between 0 and –15 percent values, favorable or unfavorable production may result according to the extent of the anomalies at the start of season in the north. Years such as 1993 and 2005 were not declared drought years because of the autumn rains in the north. On the other hand, 2013 was a drought year with more than 15 percent less precipitation overall but around 12 percent more rainfall in the north. Unfavorable years corresponded to a negative anomaly start-of-season precipitation deficit, whereas in years with a more favorable positive anomaly, start-of-season yields were not affected as strongly.

This analysis highlights the variability and frequency of droughts in Tunisia and that the timing of the dry period is important in determining the long-term effects. Given the dominance of rain-fed cereal production in the north of the country, which contributes more than 85 percent of the national cereal output, and timing of soil tillage in the period August to November, it is not surprising that drought in this area and at that time has a notable impact. Drought occurring later in the year, following a wet, normal, or even just less-than-normal autumn, has less effect on cereal production. The data do not reveal an increasing number of negative anomalies (more droughts), but they do reveal lower precipitation during wet years.

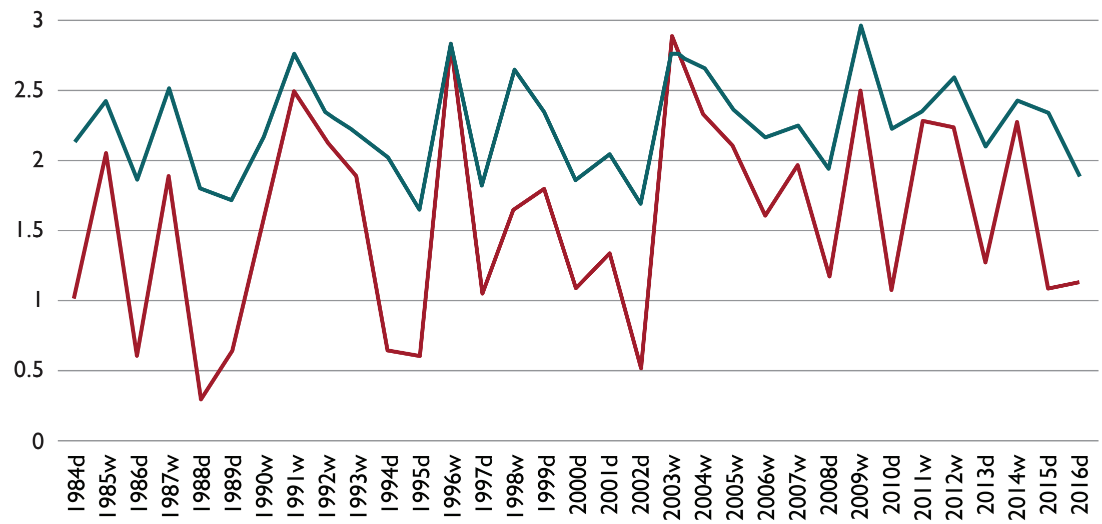
The 2016 drought caused a decline of 285,000 ha in harvested area for cereals and fodder and 4,765 ha for seasonal tomato because of restricted irrigation from dams. The grain cereals production gap was about half a million tons, and imports reached 3.3 million tons. Olive oil production declined by 28 percent, and oil mills functioned at only 40 percent of capacity. This had important economic consequences for the balance of trade because olive oil, mainly from rain-fed production, represents Tunisia's most important export product in terms of value, as indicated in Table 3.3 (http://www.onagri.nat.tn/balances, 2016). Several diseases during this period also affected small ruminants, and a vast vaccination program was undertaken in response. Hay prices doubled, which pushed smallholder herders to sell female animals at half price, leading to a significant decline in their numbers. Although meat production was unaffected and no data are available at present, it is expected that herds could decline by 20 percent in 2017.

In more general terms, considering that most agriculture in the country is rain-fed (ONAGRI, 2014), it is likewise not surprising that crop production is greatly influenced by climate variability. National cereals production between 1984 and 2016 shows marked interseasonal variability, with a saw-toothed shape and overall variation about 45 percent around the average annual production of 1.599 million tons. The maximum output of around 2.904 million tons, corresponding to 60 to 80 percent country self-sufficiency in cereals for food and feed grains, has been reached only twice over this 33-year period (FAOSTAT, 2016). Yield levels, in turn, have varied from 2 tons per ha (2002–03) to as low as 0.64 tons per ha (1987–88).

The data also show that 15 seasons of the 33 considered (45.4 percent) produced less grain than average, with the government declaring drought in 11 of those season. In those years, minimum production values were lower than 1.36 million tons (15 percent below average), suggesting that this is a likely threshold used for decisions regarding compensation to those in stressed localities. The importance of rainfall anomalies with respect to grain yields is shown graphically in Figure 3.8. Cereal production is most highly correlated with precipitation during the rainy season from September to May ($r > 0.871$). Wheat production is +0.799 correlated with precipitation during sowing and early vigor stages for cereals (September to January), whereas barley production is most correlated with end-of-season precipitation.

During drought periods, especially those occurring in the autumn, the typical response of farmers in cereal production areas is to convert the fields where little crop growth has taken place to fallow pastures for small ruminants. The observed rate of this conversion, especially in early spring, is an important indicator

FIGURE 3.8 Variation in Overall Cereal Production in Million Tons (Durum and Bread Wheat and Barley, *red line*) in Relation to Total Nine-Month Precipitation (September to May, *blue line*, unit equal to 250 mm) Over the Country (r = 0.89)



Source: ICBA, 2017.

to the government of anticipated wheat import requirements for the year. When the total area converted is above 30 percent, this has critical implications for the domestically grown food supply for the coming year. No actual figures are available for this phenomenon, but the practice is widely observed in the field.

With other crops, droughts accompanied by greater heat bring a variety of impacts. These, however, all lead to reductions in yields, which ultimately result both in production gaps for local consumption and limits to exports. For winter vegetables, growing cycles are reduced, leading to lower biomass. With olives, the effects of drought and heat depend on timing:

(i) heat during winter causes a reduction in floral induction with any deficit in residual soil moisture from the autumn season, leading to a reduction in the constitution of trunk reserves that accentuates interyear yield variation;
(ii) prolonged juvenility of young plantations that delays entrance to production (longer than eight years); and
(iii) plantation failure due to extreme stem dehydration, leading to yield reductions.

For fruit orchards, in turn, spring droughts affect flowering capacity and thus lead to reduction in fruit yields, especially for apples and pears. Winter droughts affect peach and pear vigor and flower fecundation. Citrus plantations are generally well irrigated and less infected by diseases during droughts, leading to higher yields during dry years. However, the occurrence of subsequent dry seasons can cause well salinization, which damages fructification. On a broader scale, interviews carried out by International Center for Biosaline Agriculture (ICBA) and the University of Nebraska Lincoln (UNL) in February–May 2016 with farmer stakeholders regarding drought impacts over time highlighted three main types of changes, which are discussed here.

Agricultural and social practices. Farming stakeholders reported that financial, labor, and resource availability constraints push them toward agricultural practices focused on short-term profits and expediency rather than resilience planning and longer-term sustainability. There has been an increased abandonment of livestock herding for intensive production or cereals monoculture, with tilled pastures no longer part of farming systems. The stresses on mountainous farming systems, exacerbated in particular during droughts, have also led to a major exodus of these farmers because the circumstances have proven too difficult for such farmers to sustain their rural livelihoods when drought occurs.

Those interviewed also stated that subsidy structures do not provide adequate incentives for adaptation of resilience-promoting equipment (for example, soil tillage equipment that limits erosion), techniques, and practices (such as crop diversification and integration of livestock). Subsidies exist for digging wells and installing drip irrigation, which can support crops during periods of water stress, but groundwater governance systems are not in place to ensure that these actions do not have long-term adverse impacts on available water resources. Medium-scale farmers have been able to access recently created hay fodder markets and investment capital for storage facilities. However, small farmers do not have the ability to access these resources because of their limited assets for guarantee purposes.

There has also been a more general movement away from cereal-based systems to olive/almond orchards, which have been found to be more drought resilient. This is the case for both small and medium farms. There have likewise been subsidies for tractors and harvesters to support farmers moving into olive production, and this is likely to help them to maintain an income source during drought years. Similarly, there has been a shift from winter vegetable production to tobacco, spices, tomato, and peppers, which are less affected by autumn droughts because these crops are mainly sown in early spring and rely on continuous irrigation.

More generally, stakeholders mentioned that traditional practices, such as rainwater harvesting, seed preservation, and personal livestock fodder storage, have not continued in the modern era even though they are important for increasing drought resilience. Funding is available for investment in farm infrastructure on medium and large farms through medium- and long-term bank credit that is not related to drought circumstances. However, recurrent drought events have negatively affected farmers' capacity for such investment.

Reduced resilience. Farmers and civil society stakeholders described a relative weakening of resilience in the face of drought over the past 20 years, especially in Sidi Bizoud, Kairouan, and Kasserine, as well as in poorer areas of Beja, Kef, and Siliana. According to these interviewees, the primary reasons for this were the overexploitation of groundwater resources, which are the primary buffer for drought impacts in most areas, together with the weakening of government-funded safety nets and changes in agricultural and social practices. Poor transport, electricity, water storage, and supply infrastructure compound these problems.

Maladapted crop varieties. Finally, farmers and government officials in all areas emphasized the need for crop varieties better suited to the overall climate and local microclimates in particular. They affirmed that new high-yield crop varieties (especially for cereals and fodder crops) are vastly superior to traditionally cultivated varieties, such as high straw cereals, in irrigated areas and in years with good precipitation volumes. However, in suboptimal years, these varieties produce little, whereas traditionally cultivated varieties have stable, but low, outputs. Thus, the trade-off between good-year high yields and drought-year crop survival is an important consideration for many farmers. Any changes in cropping to support the adoption of more drought-tolerant crops would require better extension services

and subsidy systems than those currently in place. The move toward the expansion of olive and fruit orchards, which are more easily irrigated and offer higher returns, has also been part of the drought adaptation strategies employed.

3.4 CLIMATE AND DROUGHT IMPACTS ON KEY AGRICULTURAL VALUE CHAINS

Two agricultural value chains, wheat and dairy products, were selected for more detailed analysis, including with respect to how they are currently being affected and likely they are to be further affected by recurrent droughts and other effects associated with global climate change. They were chosen based on their significance both for domestic food security and for the Tunisian economy as a whole. Their economic importance and prospects are the subject of a broader analysis in a parallel report on Tunisian agriculture (World Bank, 2017). This section draws primarily on the findings of that report with regard to the effects of droughts and climate change on each of these value chains following some introductory paragraphs on their relative importance in the agricultural sector and for the economy as a whole. Two neighboring governorates with distinct ecological conditions were specifically surveyed for wheat (Beja in the north and Siliana in the center) and one (Jendouba) for the dairy sector. Both rain-fed and irrigated farms were surveyed as part of this research.

3.4.1 Climate Change Impact on Wheat Production

General Characteristics

Wheat is a leading crop for Tunisian agriculture and, along with olives and tomatoes, routinely ranks among the top three crops produced annually. In 2014, wheat ranked first for quantity produced (18 percent of total national crop production) and second for harvested area (20 percent of total national crop area, behind olives) (Global Development Solutions 2017b analysis of FAOSTAT data). However, the country's wheat production varies significantly from year to year. During the 2007–16 period, Tunisia produced on average 1.2 million metric tons (MTs) of wheat annually on harvested area ranging from 434,400 ha to 961,500 ha (with an average 639,000 ha), peaking in 2009 (Figure 0.2 and Table 3.6). Wheat production quantity fell 24 percent from 2007 to 2016 and remains largely in lockstep with harvested area, as the yield rate is relatively unchanged (2.0 MT/ha in 2016).

Irrigated fields represent less than 15 percent of the total wheat crops planted, so Tunisia's wheat production depends highly on rainfall, varying annually in line with rainfall quantity and timing.[31] In 2015 and 2016, production was low because of water scarcity. Production fell from 1,513,000 MT in 2014 (445.7 mm rainfall during crop season) to 912,000 MT in 2015 (611.1 mm seasonal rainfall) to 1,100 MT in 2016 (549.5 mm seasonal rainfall).[32] The longer-term trend for wheat production shows

[31] "Recent rain eases farmers' concerns in the Maghreb," *The Arab Weekly*, January 22, 2016; http://www.thearabweekly.com/Opinion/3466/manifest.html

[32] Total rainfall between December and May in Beja, Tunisia. The absence of correlation between rainfall rate and total production also indicates other limiting factors related to crop management, such as plant nutrition, pests, and disease control (Latiri, K., J. P. Lhomme, M. Annabi, and T. L. Setter. 2010. "Wheat Production in Tunisia: Progress, Inter-annual Variability and Relation to Rainfall." *European Journal of Agronomy*, 33: 33–42. doi: 10.1016/j.eja.2010.02.004

TABLE 3.6 Tunisia Wheat Supply and Distribution, 2007 to 2016

Metric	Unit	Year										Percent Change
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2007–2016
Area harvested	1000 ha	796	535	786	434	772	754	516	703	546	550	–30.9
Production	1000 MT	1,443	919	1,654	822	1,605	1,523	975	1,513	912	1,100	–23.8
Yield rate	MT/ha	1.8	1.7	2.1	1.9	2.1	2.0	1.9	2.2	1.7	2.0	10.3
Domestic consumption	1000 MT	3,350	2,825	2,900	2,850	2,850	2,875	2,875	2,900	2,900	2,925	–12.7
FSI use	1000 MT	2,750	2,775	2,800	2,825	2,825	2,850	2,850	2,875	2,875	2,900	5.5
Animal feed use	1000 MT	600	50	100	25	25	25	25	25	25	25	–95.8
Beginning stocks	1000 MT	779	1,244	915	1,296	1,066	1,208	1,441	1,121	1,298	1,073	37.7
Imports	1000 MT	2,372	1,768	1,531	1,818	1,473	1,523	1,634	1,461	1,975	1,700	–28.3
Expats	1000 MT	100	59	46	17	24	150	20	15	25	15	–85.0
Ending stocks	1000 MT	968	771	1,010	783	987	1,008	722	781	743	603	–37.7
Percent of annual supply												
Production	Percent	32.7	25.1	41.8	22.5	41.6	37.8	27.0	40.9	24.9	31.0	–4.9
Domestic consumption	Percent	75.8	77.3	73.3	78.1	73.8	71.3	79.5	78.5	79.1	82.6	8.9
FSI use	Percent	62.2	75.9	70.8	77.4	73.2	70.7	78.8	77.8	78.4	81.9	31.5
Animal feed use	Percent	13.6	1.4	2.5	0.7	0.6	0.6	0.7	0.7	0.7	0.7	–94.8
Beginning stocks	Percent	17.6	34.0	23.1	35.5	27.6	30.0	39.8	30.3	35.4	30.3	71.8
Imports	Percent	53.7	48.4	38.7	49.8	38.2	37.8	45.2	39.5	53.8	48.0	–10.6
Exports	Percent	2.3	1.6	1.2	0.5	0.6	3.7	0.6	0.4	0.7	0.4	–81.3
Ending stocks	Percent	21.9	21.1	25.5	21.5	25.6	25.0	20.0	21.1	20.3	17.0	–22.3

Source: Global Development Solutions 2017b analysis of Production, Supply and Distribution (PSD) Data Sets: Grains, United States Department of Agriculture (USDA) Foreign Agricultural Service (FAS), January 12, 2017, https://apps.fas.usda.gov/psdonline/downloads/archives/2017/01/psd_grains_pulses_csv.zip
Note: FSI = food, seed, and industrial.

a 31 percent decline in harvested area and a 24 percent decline in production quantity over the 10-year period 2007–16, with average annual production of 1,247,000 MT on 639,000 ha. On a positive note, yield rates (across both durum and soft wheat) rose 10 percent during the period 2007–16 (range, 1.7 to 2.2 MT/ha) and reached 2.0 MT/ha in 2016.

Tunisia's wheat production is predominately in the north and center regions of the country, where cultivation conditions, including rainfall, are more favorable (Figure 0.3). Even within the north, cultivation conditions vary. Data indicated in the maps and discrepancies between planted area and harvested quantity imply, for example, that Beja governorate is significantly more productive than is Siliana in terms of yield rate.

Nationally, wheat is planted approximately mid-October to mid-December and harvested in June to July. In Beja and Siliana, both durum and soft wheat typically are planted mid-November to mid-December. Harvest begins mid-June and runs through mid-July in Siliana and end of July in Beja (Cereals Cropping Calendar, Global Development Solutions 2017b). The season for wheat roughly coincides with that of barley, another cereal crop.

Over 248,000 farmers produce nearly 1.1 million MT of wheat cultivated on 546,000 ha of land. More than 62 percent of wheat production is undertaken by smallholder farmers with less than 10 ha of

land. Farmers use retained or purchased seeds to grow wheat. Those purchasing seeds commonly purchase seeds from seed cooperatives and may produce seeds under contract for the cooperatives, with the farmer receiving seeds on credit at the beginning of the season and selling all or a portion of the harvest back to cooperatives for future sales. The public sector provides technical and financial support to the wheat sector. The value chain assessment revealed that the private sector supports farmers as well.

The majority (70 percent) of wheat farmers surveyed received technical assistance through extension services to support their crop production. Extension services reportedly were more pervasive in Beja than in Siliana, with 92 percent of Beja farmers receiving technical support from extension services compared with 45 percent reporting the same in Siliana. Various organizations provide extension services, including Regional Offices of Agricultural Development (CRDA) and their corresponding District Offices of Agricultural Development (CTVs) and the Ministry of Agriculture's National Institute for Field Crops (INGC). In addition to visiting farms and holding seminars, INGC provides information via SMS (short message service) regarding various farming tips, such as when and how to irrigate and information on pests and diseases. The service is appreciated by the farmers. Limited assistance from off-farm sources other than extension services includes buyers (8 percent of Beja farms reporting assistance from the seed cooperative COSEM, which sells seeds and contracts farmers to produce them). A small percent of Siliana farmers (9 percent) reported technical assistance from other sources, identified as suppliers (such as of fertilizers and pesticides), whereas 8 percent of Beja farmers reported other sources but did not specify them. No fees were charged for any of the services provided.

Impacts of Climate Change and Drought

The wheat sector in Tunisia is vulnerable to climate change, particularly through increasing water scarcity, variability in rainfall timing, and frequency and severity of drought. In the north region of Tunisia, the water requirement for wheat is 4,980 m3/ha. Nationwide, wheat is the product with the highest single contribution to Tunisia's water footprint related to consumption, with a water footprint of 480 m^3/year per capita. Tunisia's wheat production is highly correlated not only with the quantity but also the timing of rainfall. Specifically, yields are subject to high year-to-year variation with extremely low values in dry years. Yield is well correlated to growing season rainfall (November to May, with R2 = 0.39 for the north and 0.26 for the center/south regions) and mainly to autumn rainfall (November to January, with R2 = 0.25 in the north), whereas the correlation to spring rainfall remains extremely low, showing that the first stages of development (germination, young seedling, root establishment, and early vigor) have a determinant effect on the final yield. Drought affects the early processes and, through them, the final yield as well as sunk costs (Latiri et al. 2010).

In the north region, the sown area does not vary significantly from one year to another. On the other hand, in the center and south regions, where drought occurs frequently and sowing is postponed until the first significant rainfalls take place, there is a large annual variation in the sown area because farmers often cancel sowing. Additionally, when there is severe drought during the growing season, crop failure results in a difference between sown and harvested area. Such variations in sown and harvested areas and consequently in wheat production could become more common in the north in the future as a result of the predicted increases in drought frequency caused by climate change.

Rapid value chain assessment (RVCA) was carried out for this study on wheat with regard to the impact of climate change on surveyed farmers. Because questions were framed in the context of the RVCA concerning farmers' own wheat farming experiences, the time frame comprises the past five years,

not the long-term (scientific) definition of climate change. In this context, respondents typically report on the effects of heat stress and water scarcity, which are also predicted to increase over time because of climate change. These results are farmers' perceptions rather than scientific measurements of climate change impact.

As stated, an estimated 15 percent of Tunisia wheat production is "irrigated," meaning that it has access to irrigation water through public or private schemes. Moreover, producers in Beja and Siliana noted that wheat irrigation is supplemental, not the primary source of water for the crop. As such, both irrigated and nonirrigated wheat crops depend highly on rainfall timing and quantity. Farms that irrigated did so one to ten times per season and used a sprinkler (aspirator) system.[33] Use of irrigation water was low because of cost and time (for water and labor for equipment set-up[34]), water availability (water rationing in the public irrigation scheme), and inadequate pump functionality (public scheme pumps are in need of rehabilitation and overhaul to provide adequate and consistent water pressure to the farms).[35] Data from the National Agricultural Observatory (ONAGRI) confirm that, at most, only 25 percent of the wheat area within the irrigation perimeter actually uses irrigation resources (ONAGRI, 2011).

According to the Global Yield Gap Atlas,[36] the potential yield rate in Tunisia for rain-fed wheat varied from 2.1 to 6.0 MT/ha during the period 2004–11, based on the available water via rainfall and assuming optimal agronomic management (for example, optimum sowing dates, plant density, and cultivar maturity, etc.). During the same period, actual average yield rate (adjusted for standard moisture content) ranged from 0.1 to 0.9 MT/ha, resulting in a gap in the yield rate (that is, a difference between actual and potential production) of 1.6 to 5.3 MT/ha per year. The yield rate gap continues to narrow between optimal and actual yield rate, but the gap is still large (Figure 3.9), which calls for the need to improve farming techniques and technical assistance to improve agronomic practices. Further, the potential rain-fed yield rate fell 38 percent from 2004 to 2011, implying that wheat cultivation has become increasingly difficult given natural rain resources.

The yield rate gap for irrigated wheat remained largely constant from 2004 to 2013 (average 4.1 MT/ha; range 3.1 to 6.6 MT/ha). According to the Global Yield Gap Atlas, the potential irrigated yield rate in Tunisia rose 6.2 percent during 2004–13 (from 5.87 to 6.24 MT/ha). The actual yield rate for irrigated wheat fell 7.2 percent during 2004–13 (from 2.54 to 2.36 MT/ha). As with rain-fed wheat, technical assistance and improved farming techniques are needed to close the gap. The consistent gap between theoretical and actual yield rate under irrigated wheat production implies that cultivation inputs and techniques have not improved over the past decade. Sector support appears to have been neglected, other than for subsidy/price supports. For example, the number of extension officers in Beja declined from

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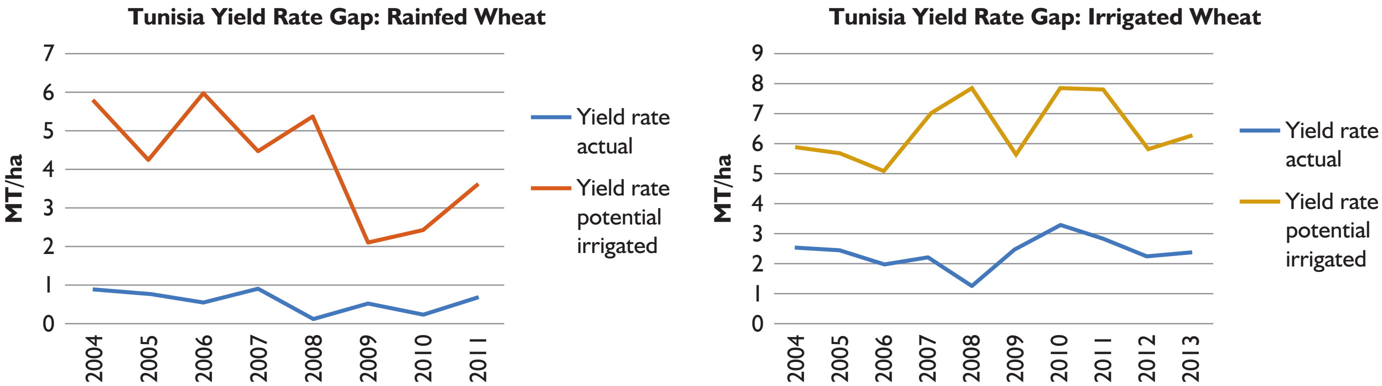
[33] Sprinkler (overhead) system is defined according to AQUASTAT, FAO: http://www.fao.org/nr/water/aquastat/investment/print1.stm as a pipe network through which water moves under pressure before being delivered to the crop via sprinkler nozzles. The system simulates rainfall in that water is applied through overhead spraying.

[34] Irrigation via aspirator/sprinkler for wheat in the target regions requires manually setting up, irrigating and moving equipment, with one portion (for example, 0.5 to 10 ha/day) of the wheat farm being irrigated at a time. Farms typically hire temporary labor specifically for irrigation placement. Depending on farm size, an irrigation cycle can take several days/weeks for a single farm.

[35] Farmers within a public irrigation scheme do not have their own pumps. Each scheme has two or three pumping stations that theoretically provide enough pressure to deliver water efficiently to the farms and onto crops. In practice, however, the pumping stations are antiquated and in need of repair/replacement, and some farmers reported insufficient water pressure to irrigate.

[36] The Global Yield Gap Atlas determines a potential yield if optimal agronomic management and ideal conditions are followed. http://www.yieldgap.org/

FIGURE 3.9 Tunisia Yield Rate Gap for Rain-fed and Irrigated Wheat



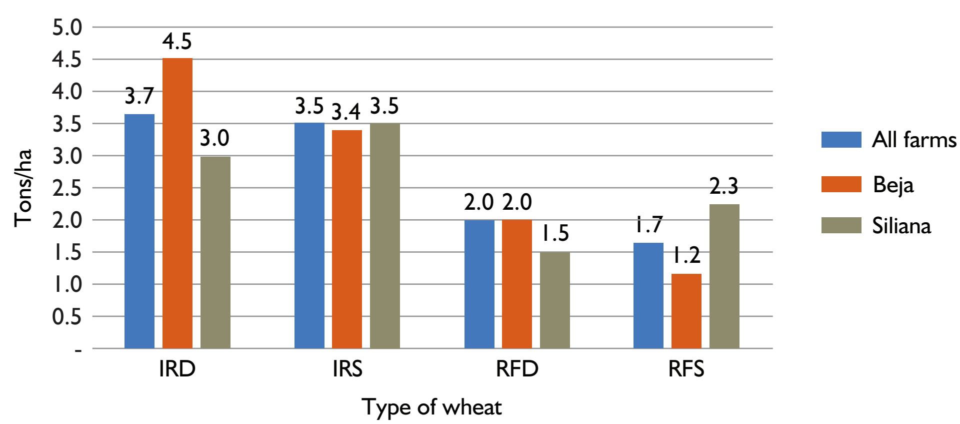
Source: Global Development Solutions 2017c analysis of Global Yield Gap Atlas data: http://www.yieldgap.org

52 in 1992 to 30 in 2017, with positions of retired officers not refilled. Further, CTVs rely on historical experience but are challenged to provide current information or to liaise with research organizations, given the lack of internet at CTVs.

The 2016 harvest suffered from a second year of low rainfall, as well as low recharge of dams supplying irrigation schemes and subsequent curtailment of irrigation water to supply drinking water. As a result, growers reported yield rates in 2015 and 2016 fell 50 to 60 percent for rain-fed and 0 to 40 percent for irrigated wheat from 2014 results. Survey results for wheat production per hectare for Beja and Siliana in 2015–16, shown in Figure 3.10, clearly indicate that irrigated wheat has significantly higher yield rates than does rain-fed wheat. Within the same governorate, the difference in yield rate can be as much as two times or more. As an example, in Beja irrigated durum wheat yield is 225 percent higher than that of rain-fed durum wheat.

Farmers were asked whether yields have changed over the past several years. As Figure 3.11 indicates, there is a continuing decline in yield, which is particularly true for rain-fed wheat in Beja, where 58 percent of the farmers said their yields have declined.

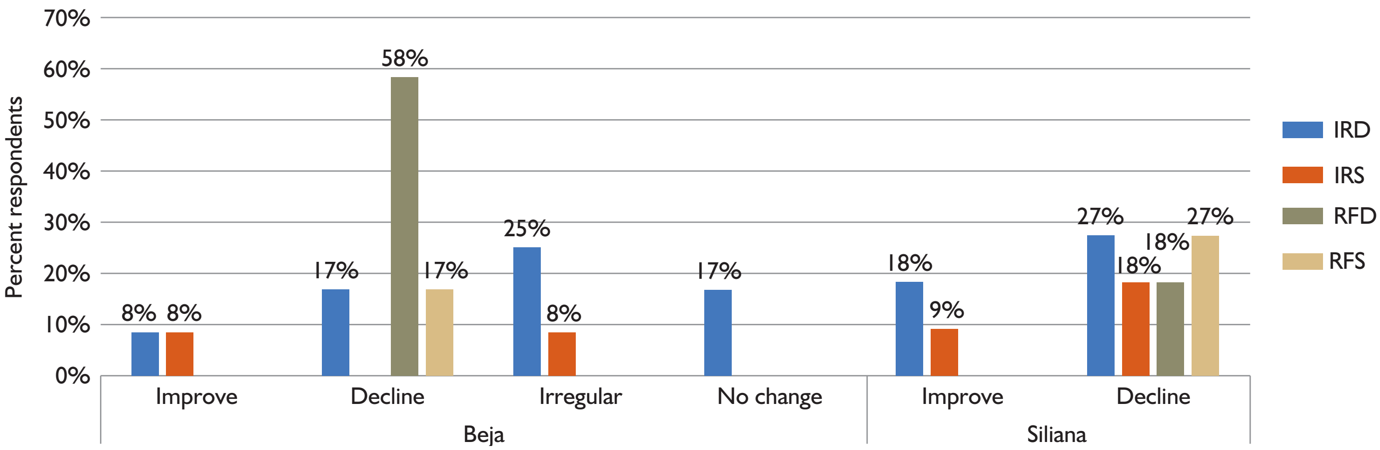
FIGURE 3.10 Yield Rate, Irrigated versus Rain-fed Durum and Soft Wheat



Source: Global Development Solutions 2017c.

Notes: IRD: Irrigated durum wheat; IRS: Irrigated soft wheat; RFD: Rain-fed durum wheat; RFS: Rain-fed soft wheat.

FIGURE 3.11 Change in Wheat Yield Rate over Past Several Years



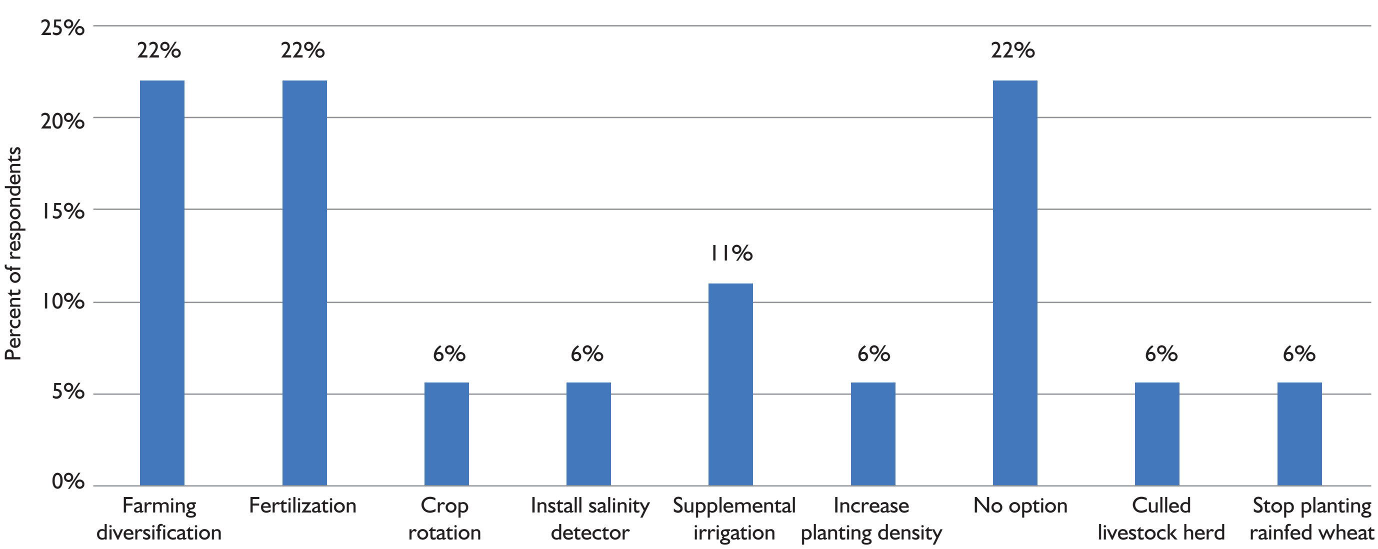
Source: Global Development Solutions 2017c.

Notes: IRD: Irrigated durum wheat; IRS: Irrigated soft wheat; RFD: Rain-fed durum wheat; RFS: Rain-fed soft wheat.

By far, the main factor to which farmers attributed declining crop yields is the lack of rain over the past several years, with 84 percent of the farmers identifying this reason. A fifth of farmers indicate that lack of irrigation water is a factor, and a fifth also attribute declining yields to increasing salinity of irrigation water. According to the farmers, the low rainfall/lack of water contributes to increasing irrigation water salinity. Although water tariffs are reduced for cereals (for example, Beja growers in the irrigation perimeter reported that wheat and barley rates are TD 0.063/m^3, or half the noncereal crop rate of TD 0.126/m^3), 5 percent of growers still see cost as an obstacle to wheat irrigation, particularly when considering labor costs and time to set up the irrigation equipment (Global Development Solutions 2017c).

Farmers have implemented a variety of actions in response to the lack of water and issues related to declining wheat yields. Figure 3.12 lists the actions taken by farmers. Actions include diversifying

FIGURE 3.12 Adaptive Measures Taken in Response to Declining Wheat Yield



Source: Global Development Solutions 2017c.

farming activities, which includes farming high-value horticulture. For example, tomatoes can tolerate higher salinity levels. Other field crop options include planting barley, which has a lower water requirement than does wheat. Another relatively common option was to apply organic fertilizers that supposedly have better water retention properties. However, some farmers found themselves in a situation in which nothing could be done to alleviate the prevailing climatic conditions.

Of the farmers interviewed who plant on irrigated land, 100 percent are in a public irrigation scheme. Eighty-four percent of farmers responded that the water supply for their irrigation scheme has decreased. The main reason given was again the lack of rainfall, which caused the dams and irrigation systems to run extremely low and sometimes stop working altogether. These findings suggest that merely participating in an irrigation scheme no longer guarantees improved yields and that alternative cropping options need to be introduced. Adaptive measures taken by farmers include skipping a planting season, reducing the area of wheat cultivation (with farmers switching to barley, a more drought-tolerant crop), purchasing a water tank for supplemental irrigation, and general reduction of water use.

Although the unit cost of water has not changed over the past few years, the associated costs with the lack of rain have led to increased costs in the form of additional labor needed to set up the irrigation equipment. Aspirators are capable of irrigating only about half a hectare at a time, and proportionately less when water pressure drops, and need to be moved to different locations around the farm. Moving and setup costs for equipment can amount to one person-day (at a cost of approximately TD 15) per hectare. Eighty-five percent of the farmers in an irrigation scheme have their wheat within the irrigation perimeter. Of those, 29 percent said there was no water in their irrigation perimeter.

All farms with irrigation use movable system/aspiration. Water comes from various sources, the most common (86 percent of respondents) being public irrigation schemes, followed by rivers (21 percent), dams (14 percent), cisterns and wells (7 percent each). Because of lack of water, 47 percent of farmers did not use the irrigation system during the previous season. Irrigation cycles ranged from none to as many as 10 per season. Only one farmer irrigated 10 times, using a cistern. No farmer irrigated more than five times in the previous season. Median per-hectare water usage for surveyed farms was 23 m^3.[37]

3.4.2 Climate Change Impact on Dairy Production

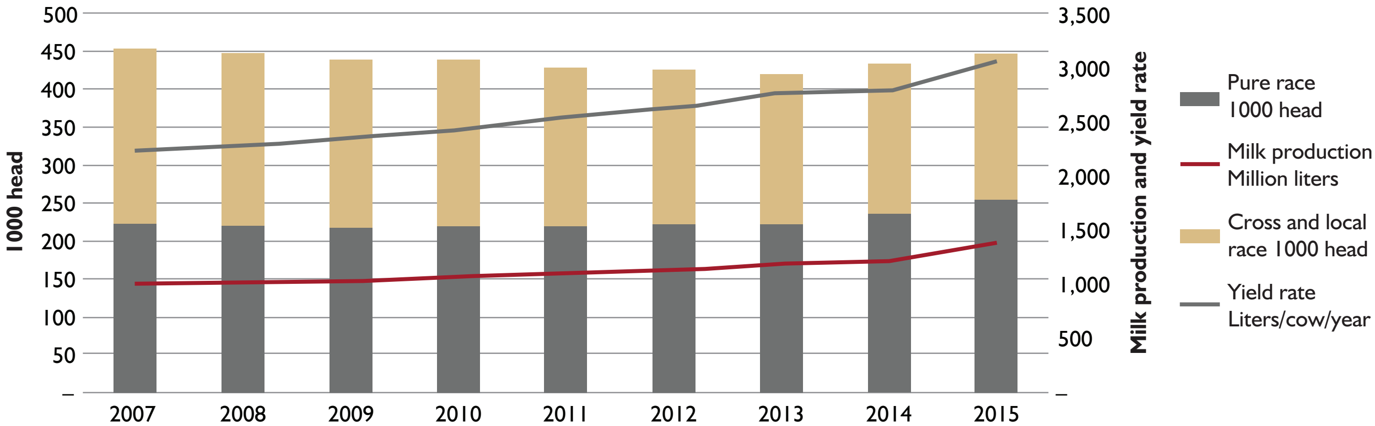
General Characteristics

The Tunisian dairy sector accounts for 11 percent of agriculture production value, 25 percent of livestock production value, and 7 percent of agribusiness value. The sector is estimated to account for 40 percent of workdays in the agriculture sector. Nearly one in three Tunisian farms produces milk (GIVLAIT 2017).

Tunisia's total milk production increased 37 percent from 1.0 billion liters in 2007 to 1.4 billion liters in 2015 (Figure 3.13). Although the total number of cows remained essentially flat, the number of cows of improved breed (pure breed, primarily Holstein) rose by 16 percent, to 58 percent of the total cattle population, whereas those of cross or local breeds fell by 17 percent. Commensurate with breed improvement, yield rates increased to 3,058 liters/cow/year. The share of milk collected reached 62 percent in 2015. Milk that is not collected is used on farms (that is, for household or animal consumption) or sold informally.

[37] Surveyed farmers reported a wide range of per-hectare water usage and the associated cost per cubic meter, which is a possible indication that farmers do not have a firm grasp regarding how much water they use. This further leads to a notion that farmers may not fully understand the correlation between water and yield (Global Development Solutions 2017c).

FIGURE 3.13 Evolution of Tunisian Milk Production, 2007 to 2015



Source: Global Development Solutions 2017b analysis of data from Présentation de la Filière Laitère en Tunisie et Chaine de Valeur du Lait de boisson UHT, Le Groupement Interprofessionnel des Viandes Rouges et du Lait (Interprofessional Group for Red Meat and Milk) (GIVLAIT), February 15, 2017.

Milk productivity per cow (liters/cow/year) is estimated at 4,200 liters for pure breed (most common breed Holstein), 1,100 liters for cross breed, and 600 liters for local breed. Tunisian Holstein cows achieve milk productivity of 4,500 to 11,000 kg/cow/year. In contrast, in France, Holstein cows yield up to 20,000 kg/cow/year. Approximately 112,200 cattle farmers with an estimated cattle population of approximately 436,000 produce cow's milk in Tunisia. Approximately 73 percent of farmers operate cattle farms with less than 10 ha of land, and over half of these farmers have less than 5 ha of land (Table 3.7). Over 93 percent of cattle farmers have less than 10 cows, and 82.8 percent have fewer than five, which clearly indicates that Tunisia's dairy sector is composed predominantly of smallholder cattle farmers.

There are three types of dairy farming systems in Tunisia based on farm holding structure and the type of livestock management and diet: extensive, integrated, and landless (Table 3.8). Of these, only extensive and integrated were observed in Jendouba. Many surveyed farms took a hybrid approach (a combination of extensive and integrated characteristics): for example, feeding is done with both grazed and purchased feed or paid labor supplements family labor. Productivity of traditional/extensive production is usually less than 2,000 liters/cow/year, a figure that is low because of poor seasonal feeding and overstocking. Integrated/intensive production achieves higher yield rates (3,000 or more liters/cow/year), but farmers must supplement cows' diet with concentrates given the poor quality of locally produced fodder (LACTIMED 2013).

Five governorates (Beja, Bizerte, Jendouba, Nabeul, and Sidi Bouzid) produce more than half of Tunisia's raw cow milk, with Bizerte the top producer (13 percent of the national total), followed by Jendouba (11 percent). Milk production is estimated because only collected milk is measured, and uncollected milk (approximately 38 percent of national production) is retained (that is, used for household or livestock consumption) or traded informally, so it is not officially measured.

Collection from farmers of all raw milk intended for industrial processing is via a national collection network overseen by the Office of Livestock and Pasture (OEP), agricultural service

TABLE 3.7 Distribution of Dairy Farms and Cows, 2013

Hand Holding	Percent of Total	No. of Cows	Percent of Total
≤ 5 ha	51.6	1–5	82.8
5–10 ha	21.8	6–10	10.9
10–50 ha	22.7	11–20	4.8
50–100 ha	2.4	21–50	1.3
≥ 100 ha	1.3	≥50	0.2

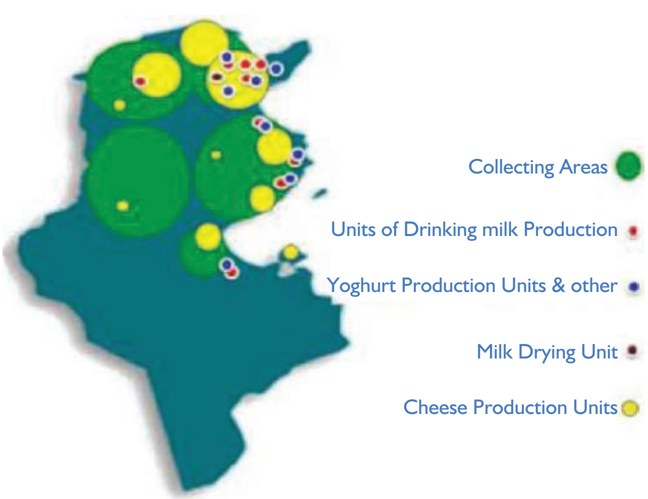
Source: LACTIMED 2013.

TABLE 3.8 Tunisian Milk Farming Systems

	Extensive	Integrated	"Landless"
Main location	North	North	Sahel (centre)
Fodder area	> 1 ha/cow	0.25 ha–0.75 ha/ cow	0–0.20 ha
Cattle breed	Local/cross	Holstein-Frieslan	Holstein-Friesian
Herd size	1–20 cows	100–1,600 cows (companies) 1–40 cows (individual farmers)	1–20 cows
Milk yield (l/cow/yr)	<2.000	3.000–6,500	3 000–6.500
Basic feed	Pasturelands	Fodder/concentrates	Concentrates
Origin of fodder	Grazing	Farm/market	Market
Origin of straw and hay	Farm	Farm/market	Market
Origin of concentrates	(Market)	Market	Market
Investment level	Zero	High	Limited
Origin of funds	Own Funds	Credit	Own funds
Mem income	Agriculture	Livestock/crops	Other activities
Type of labor	Family	Paid	Paid/family
Mode of remuneration	Family	Employee	Family
Trend	Declining	Heavy use of concentrates	Organization of the profession

Source: Adapted by LACTIMED 2013 from C. Kayouli, Country Pasture/Forage Resource Profiles Tunisia 2006, FAO, Rome.

FIGURE 3.14 Geographic Distribution of Tunisian Dairy Industry



Source: Louhichi 2013.

cooperatives, and private industrial operators (drinking milk processors, cheese producers, etc.). Collection centers exist throughout the country but are more prevalent in the north and center, in proximity to the milk producers. Collectors are private entities regulated by the government and adhere to and are compensated according to a pricing schedule. The collectors must comply with hygiene and quality standards as prescribed by OEP. Milk collection operations are broken down nationally into five areas (Figure 3.14). The largest share of collected milk is in the center-east area (32 percent of collected milk). The northwest area, including Jendouba, accounts for 20 percent of national milk collection.

Impacts of Climate Change on the Dairy Sector

The dairy sector in Tunisia is affected by changes in both temperature and water availability caused by climate change. Specifically, fodder production, watering of livestock, and milk and cheese production are all threatened by increasing temperatures and increasing water scarcity.

There is a supply gap in the amount of fodder produced in Jendouba, the target governorate for the dairy RVCA, because rain-fed production of fodder crops cannot keep up with the current herd size. If the distribution of land for fodder crops is kept constant, and assuming that the optimal feeding regime is observed, irrigated forage land would need to be increased from the current 20 percent to slightly over 48 percent of the available 26,910 ha for Jendouba to produce a sufficient volume of fodder to meet the feeding requirements for all livestock.

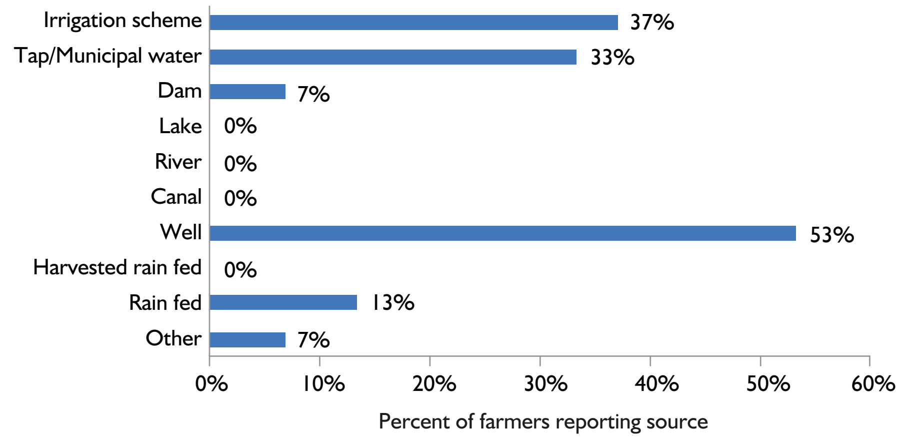
Forage amount, particle size, maturity, and fiber content also affect milk fat levels. As forage amount declines, milk fat percentage falls proportionately, which highlights the importance of ensuring that forage production and crop yield rates continue to improve to support the dietary needs of dairy cows, particularly during the dry season. Although many farmers tend to rely on mid- and late-bloom alfalfa to ensure greater volume of forage, immature alfalfa hay is required in the dairy cow's diet to obtain maximum production of 4% fat-corrected milk (Kawas et al. 1983). This suggests that more frequent cultivation of alfalfa is required, which will be reflected in an even higher demand for irrigation water. Given the high cost and unpredictability of water availability, even though irrigation schemes may be available, an alternative consideration is to promote the reduction of herd size and improve fodder production and availability, thus improving yield rate per animal and milk quality (milk fat content). Although such action may be counterintuitive and possibly find resistance among farmers and processors, improving the quality of milk and promoting a quality-based pricing structure could result in higher income for farmers and greater production and availability of higher value-added milk products in the market.

Milking cows requires a substantial amount of water to maintain regular and optimal milk output. Based on the assumption that the outside temperature stays between –3.9°C and 18.3°C (the ideal temperature range for milking cows), the total water requirement for the existing dairy cows in Jendouba is approximately 1.26 million m^3/year. However, temperatures exceed this range in the summer. At average temperatures for July and August in Jendouba, cows will double their water consumption, which translates to more than 113 liters/animal/day. Highs can reach 44°C, with humidity well above 50 percent during July and August, which will affect milk production in the absence of sufficient volume of clean water and heat mitigation measures. According to research conducted in Tunisia by the Laboratory of Forage and Animal Production, there is a close correlation among temperature, humidity, and milk production (Ben Salem and Bouraoui 2009). For a cow producing approximately 17.1 kg of milk per day, heat stress caused by outside temperatures of 26.2°C with humidity levels of 54.8 percent would decrease milk production to about 15.9 kg/day.

Water availability is also critical for the protein and fat content of milk, which determines both the quality of the milk and the potential for value-added products, such as cheese. Among smallholder farmers, for whom hygienic practices are limited, cow udder infection is relatively common; it often is caused by an unclean water supply and lack of hygienic practices. Even if farmers have been trained in and are aware of the importance of animal hygiene, the lack of access to clean water has had a limiting effect on the ability of smallholder farmers to exercise good husbandry practices. Mastitis causes decline in milk fat percentage (up to 10 percent) and a change in milk fat and protein composition (Kitchen 1981). Thus, reduction in water availability and quantity and quality of fodder have a number of negative implications for the fat and protein composition of milk and, in turn, the quality and types of cheese that can be produced from it.

Climate change impacts on dairy farmers in Tunisia were assessed by conducting a RVCA survey. As in the case of wheat discussed previously, because questions were framed in the context of the RVCA concerning farmers' own dairy farming and cheese-producing experiences, the time frame comprises the

FIGURE 3.15 Water Source for Cows and Fodder in Jendouba



Source: World Bank data.
Note: Multiple responses accepted.

past five years, not the long-term (scientific) definition of climate change. In this context, respondents typically report on the effects of heat stress and water scarcity, which are predicted to increase over time because of climate change. Thus, the results reported here are farmers' perceptions, rather than scientific measurements of climate change impact.

Of Jendouba's forage crop area of 26,910 ha, 20 percent is irrigated. A yield rate for irrigated versus rain-fed fodder could not be determined.[38] Forage crop production is limited by lack of irrigation access and lack of land because small farms (the dominant producers) grow multiple crops to support their households. Forage feeding is supplemented by purchased feed for general nutrition year-round and in times of heat stress on forage crops. Producers report that feed prices increased 23 percent over the past five years. For cows, water is used both for drinking and cooling. Data from the surveyed dairy farms varied, but the average per-cow water usage is approximately 70 liters per day, which does not include the watering requirements to grow fodder for cows.[39] This figure is well below the approximately 115 to 150 liters of drinking water per Holstein cow per day (summertime) based on studies by the University of Kansas.[40] In addition, estimates calculated specifically for Jendouba based on temperature and humidity levels, particularly during July and August, suggest that a cow would require approximately 113 liters/day (Global Development Solutions 2017c).

Among surveyed producers, 37 percent of farms were under irrigation schemes. The majority of these farms (70 percent) also supplement with water from other sources, including well, municipal water, and dams. Only 7 percent of surveyed farms are entirely rain-fed with no supplementation from other sources. The most common supplementary source is wells (53 percent), followed by municipal water supply (33 percent) (see Figure 3.15).

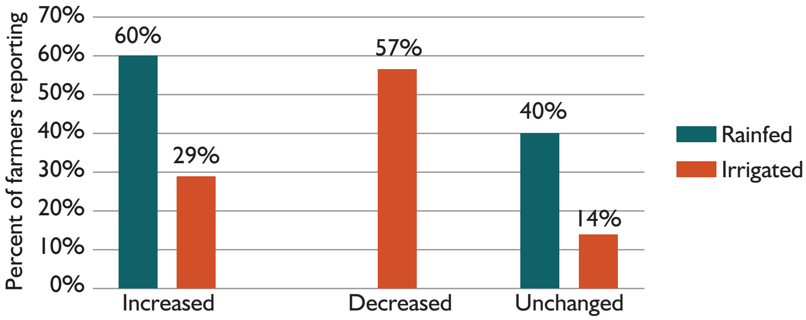
Producers indicated that cows undergo heat stress for four to five months of the year (mid-May to mid-September), during which the quantity and quality of milk falls, as does the availability of forage and

[38] Forage production quantity is not tracked by the government of Tunisia; an unknown portion is retained on-farm rather than sold and consumed on-field rather than harvested.

[39] The figure of 70 liters/cow/day takes into account the removal of an apparent outlier data point from the survey. Had the data point remained, the average would increase to approximately 85 liters/cow/day.

[40] http://krex.k-state.edu/dspace/handle/2097/6880

FIGURE 3.16 Dairy Farm Milk Yield Rate Change in Past Five Years



Source: World Bank data.

feed, and spoilage rates increase such that collectors reject milk more frequently. The heat stress, related low nutrient availability from forage, as well as the lower proportion of pure breed cows (37 percent in Jendouba versus 58 percent nationally) contribute to yield rates in Jendouba that are only 76 percent of the national average.[41] Survey data suggest that the use of irrigated land for cows or forage production did not have a strong influence on milk yield rate (7–20.7 liters/cow/day rain-fed versus 12–20.7 liters/cow/day irrigated).[42]

There is no consensus among surveyed milk producers regarding change in yield rate (liters of milk per cow per year) over the five years. Overall, 42 percent of farmers surveyed in Jendouba governorate report that their yields have increased, 33 percent report a decrease, and 25 percent indicated that their yields have not substantially changed (Figure 3.16). Surprisingly, no rain-fed producers reported a decrease in yields, despite challenges they face regarding water availability. This may be because yields were already low compared with the national average and international standards.

Changes in milk yield rate were attributed primarily to breed, changes in feed cost and availability, and heat stress. Figure 3.17 indicates producer perceptions of causes for increased yields, whereas Figure 3.18 indicates their perceptions of causes for decreased yields.

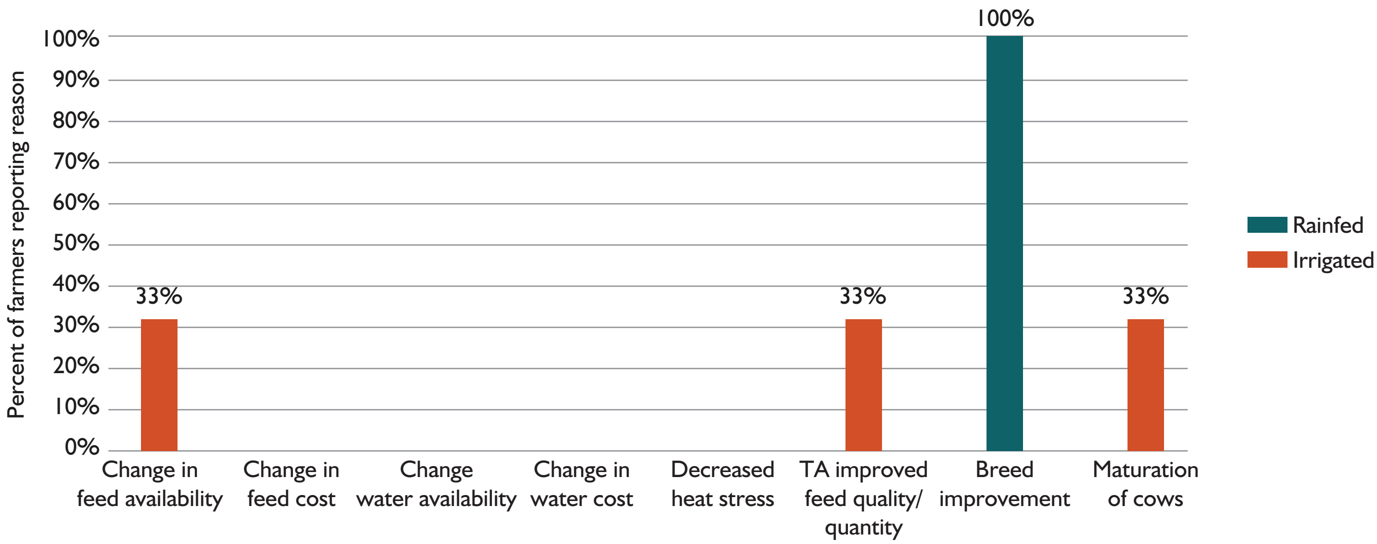
One hundred percent of rain-fed farmers who reported increased yields credited use of improved breeds for their success. Among irrigated farmers, one-third reported changes in feed availability, one-third specifically credited technical assistance and training for helping increase feed quality and quantity, and one-third attributed yield increases to the maturation of the farm's livestock. Only irrigated farmers reported decreases in yield. Of these, 80 percent blamed changes in feed availability and cost for yield declines, and 60 percent attributed decreases in yields to increased heat stress over the past five years. This may indicate a lack of understanding and/or practice of animal cooling methods, either because of the shortage of available water or lack of technical know-how.

Further, 100 percent of milk producers noted that the quality or quantity of milk per cow varies materially during the year, on a daily or month-to-month basis, for reasons other than pregnancy or

[41] Tunisia's pure breed cows are primarily Holstein. Reportedly, Holstein yield rates in Tunisia (25 liters/cow/day) are routinely half that of Holstein rates in France (45 liters/cow/day). Although the shortfall is attributed to climate (heat) and nutrition, a more climate-suitable breed has not been identified.

[42] Dairy farms with both rain-fed and irrigated forage/cropland were considered. . Farms surveyed during the mission included three categories of farm structure: (i) *Sociétés de mise en valeur et de développement agricole* (SMDVA) (agricultural development companies) (ii) *techniciens agricoles* (agriculture technicians) who farm *lots techniciens* (plots of agricultural land allocated to technicians) (LOT) and (iii) independent farms (of any size); and included CTV "focal point" farms with 100 percent pure breed cows, which contributed to higher yield rates versus the national average of 8.4 liters/cow/day.

FIGURE 3.17 Farmer Perceptions of Causes of Increased Annual Milk Yield Rate

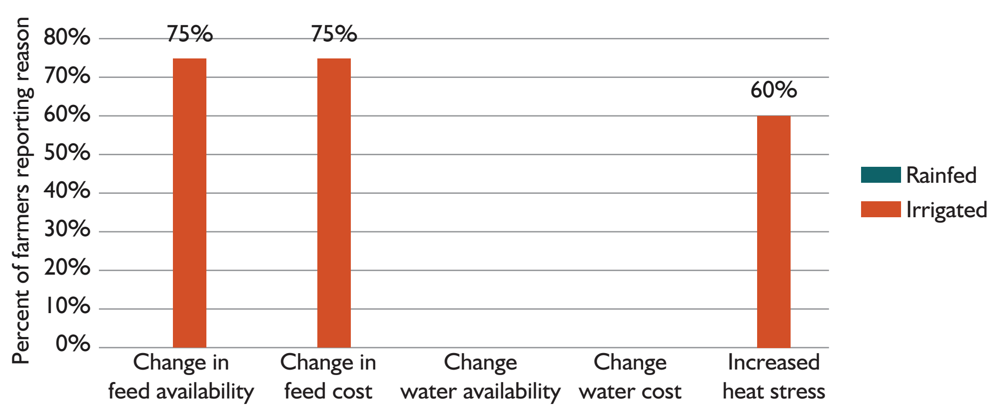


Source: World Bank data.
Note: Multiple responses accepted.

birth of a calf. Common causes cited were heat stress (80 percent of farmers surveyed), feed availability (47 percent), feed cost (7 percent), and other reasons (20 percent). Irrigated farmers perceived feed availability as somewhat more of a constraint than did rain-fed farmers, whereas rain-fed farmers found feed cost to be more problematic (Figure 3.19), likely because more rain-fed farmers must buy feed for their livestock because of the difficulty of growing fodder without irrigation.

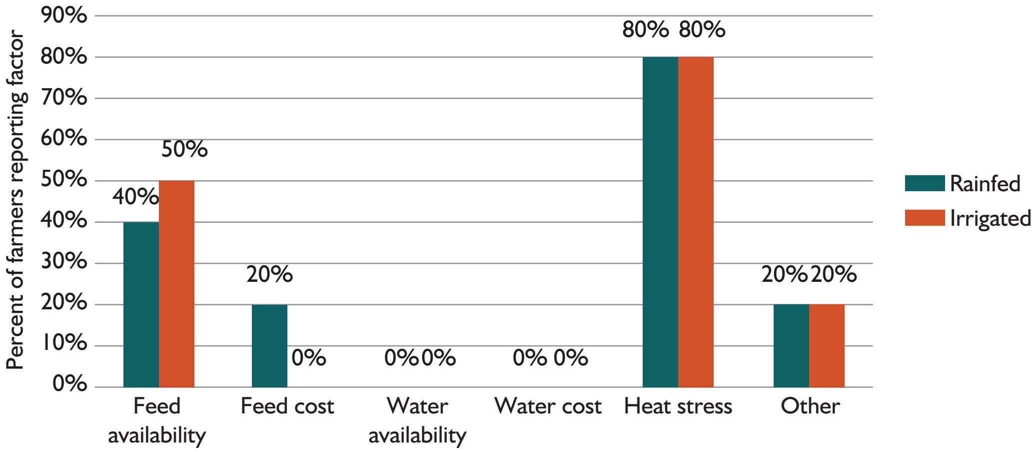
Despite that farmers do not appear to recognize water availability as a challenge to milk production, they do report that water availability is decreasing. This disconnect indicates a need for technical assistance concerning methods to combat heat stress and the amount of water needed to grow enough fodder to ensure constant availability of adequate feed. Although heat stress is a widely acknowledged problem for dairy farmers, the availability of water to mitigate the impact on livestock of rising average

FIGURE 3.18 Farmer Perceptions of Causes of Decreased Annual Milk Yield Rate



Source: World Bank data.
Note: Multiple responses accepted.

FIGURE 3.19 Farmer Perceptions of Factors Contributing to Monthly Variability in Milk Quality and/or Quantity



Source: World Bank data.
Note: Multiple responses accepted.

temperatures, especially during the summer months, is limited. None of the producers surveyed reported that water availability had increased over the past five years, despite increasing need for water. In fact, 100 percent of rain-fed farmers observed a decrease in water availability. Irrigated farmers appear to be more insulated against changes in precipitation amount and increasing water scarcity in irrigation schemes; 38 percent reported a decrease in water availability over the past five years, whereas 63 percent perceived no significant change.

In a similar vein, high ambient temperatures are problematic for milk storage. Among surveyed growers, only 33 percent (0 percent of rain-fed farms) have cooling equipment on the farm. Almost 90 percent of farms that reported milk rejection because of quality issues such as spoilage lack cooling equipment. Only 20 percent of farms with cooling equipment reported rejections attributed to spoilage.

Farmers reported taking the following adaptive measures to improve the quantity and quality of milk in the past five years: 100 percent of rain-fed farmers who took adaptive measures engaged in breed improvement through insemination. Irrigated farmers also engaged in breed improvement, although to a lesser extent (33 percent). Two-thirds of surveyed irrigated farmers who took adaptive measures acquired cooling tanks for improved milk storage, citing excessive heat in July and August.

3.4.3 Challenges and Recommendations for Climate Change Adaptation in the Wheat and Dairy Subsectors

As concerns the wheat and dairy products value chains, the key climate and drought-related challenges identified by this study and associated specific recommendations are as follows:

Wheat

- Challenge 1: The lack of rain has taken a heavy toll over the past several years, particularly on rain-fed wheat yields. Water tables are so low that irrigation schemes struggle to deliver water to the irrigation systems, and water quality is suffering from rising salinity levels.

- Recommendations: (i) conduct crop suitability study to determine the feasibility of diversifying farming practices on current wheat fields; and (ii) research the possibility of introducing new, more drought-tolerant wheat varieties.
- Challenge 2: Inadequate irrigation perimeter for wheat cultivation needs.
- Recommendation: double existing irrigation perimeter.
- Challenge 3: High cost to farmers of participating in public irrigation schemes: water quality, pumping stations should monitor quality (that is, check for salinity); cost of water; irrigation equipment and associated labor; water availability is poor; and inadequate water pressure wastes water.
- Recommendations: (i) rehabilitate pumping stations for optimal water delivery and quality control; (ii) make billing and water storage data transparent and easy to follow; and (iii) instruct farmers how to organize and maintain important water and other inputs usage and cost data.
- Challenge 4: Producer price controls on wheat encourages establishment of parallel markets for wheat.
- Recommendations: (i) improve the crop grading and pricing system to reflect and reward farmers with high-quality crops; and (ii) eliminate the price ceiling on wheat and allow the market to determine price.

Dairy Products

- Challenge 1: Inadequate irrigation perimeter for fodder.
- Recommendations: (i) double existing irrigation perimeter; (ii) change fodder crop mix to include more desert-hardy plants, which require less water; and (iii) provide technical assistance on improved forage production and range management techniques.
- Challenge 2: Increasing scarcity of clean water for animal husbandry use.
- Recommendations: (i) implement appropriate water harvesting practices at household and village levels; (ii) research drought-hardy hybrid breeds; (iii) reduce (cull) the national dairy cow herd, particularly local indigenous breeds, and either farm only high-yielding ones (for example, Holstein) or increase horticulture activity, particularly drought-tolerant varieties, or a combination of both; and (iv) introduce a quality-based milk pricing structure to reward high quality production.
- Challenge 3: Lack of finance/inadequate access to credit for cooling equipment necessitated by rising temperatures.
- Recommendations: (i) pilot financing scheme for processors to purchase milk cans for collection to be rented by farmers to deliver raw milk; (ii) expand pilot of Holstein system for on-farm milk cooling with solar energy from Sidi Bouzid; and (iii) for small independent dairy farmers, encourage purchase of shared facilities via a group lending scheme.
- Challenge 4: Knowledge gap in understanding of best practices for heat mitigation, animal health and hygiene, and optimal fodder cultivation.
- Recommendations: (i) introduce various cooling methods and techniques to reduce cow heat stress; (ii) expand extension services focused on animal hygiene, particularly targeting mastitis prevention; and (iii) improve extension support on animal nutrition and optimal feeding practices.

CHAPTER
FOUR

DROUGHT MANAGEMENT IN TUNISIA

This chapter describes the evolution and nature of Tunisia's current drought management system, giving particular attention to those elements that are intended to help mitigate drought impacts on the agricultural (including livestock) sector. It considers how the government is organized to address drought situations and briefly describes the instruments that are used in an effort to mitigate the impacts of droughts. This discussion is based on a review of existing literature and the field research with government and civil society stakeholders and subsequent analysis carried out by ICBA and the University of Nebraska in 2016; this research is referred to in the two preceding chapters. It also points out areas of good practice and continuing challenges and gaps that remain to be filled. These form the basis for the policy options that are suggested in the final chapter of this report.

4.1 INTRODUCTION

As elsewhere in the MENA region and many other parts of the world, drought is a recurrent natural phenomenon in Tunisia. Furthermore, as the two previous chapters have shown, drought events in Tunisia are likely to become more frequent and intense in the future as the result of global climate change, with particularly harmful effects on the agricultural sector and broader repercussions for the national economy as a whole. In response, the government has gradually taken a number of measures to address this situation.

This chapter describes the evolution and nature of Morocco's drought management arrangements, giving particular emphasis to those elements that are intended to help mitigate drought impacts on the agricultural (including livestock) sector. It also points out areas of good practice and gaps that remain to be filled, which will form the basis for the recommendations that are put forward in the final chapter of this report. This chapter begins with a few considerations regarding the recommended approach to national drought management policy and interventions in general based on key lessons from international experience to date.

4.2 LESSONS FROM INTERNATIONAL EXPERIENCE WITH DROUGHT MANAGEMENT

As observed in Chapter 1, in recent decades many countries have shifted their approach to drought management from one consisting largely, if not exclusively, of reactive emergency relief actions once droughts have started to a more proactive risk management approach that focuses on improved monitoring and early warning systems, together with a variety of other preparedness measures, in an effort to better anticipate and mitigate the likely local and broader harmful economic, social, and environmental effects of this recurrent climate-related phenomenon. A recent review of evolving international experience with respect to drought management (Redwood 2017) highlighted a number of lessons that are worth taking into consideration when examining drought in Tunisia. These include the following:

- Numerous countries have a long history of dealing with droughts and adapting to drought impacts. However, these efforts have occurred in a largely ad hoc and reactive manner. More recently, a drought risk management approach has been taken in many countries to help address and reduce the likely increasing serious nature of future droughts.
- Because droughts are complex phenomena and their impacts evolve as social vulnerabilities change over time, improving drought risk management requires a long-term commitment, whereas short-term projects may meet with only limited success. However, proactive risk management strategies may require years to develop and evolve to successfully reduce drought impacts.
- Long-term drought risk management can be difficult to advance when the pressure caused by a current severe drought heightens the focus on immediate crisis response. However, it is often a severe drought crisis that provides the best opportunity and impetus to implement longer-term drought risk management measures.
- Because drought risk management involves a long-term commitment, it is not uncommon for initial efforts to be comparatively simple with the expectation that they will become more sophisticated over time. A prime illustration of this is the United States Drought Monitor (USDM), which was a much simpler process when it started in 1999 (see Box 4.1). There are similar expectations in relation to the newly established drought monitor for northeast Brazil (see Figure 4.1 and Table 4.1) (De Nys, Engle, and Magalhães 2017).
- The iterative process that occurs between drought monitoring and improved drought risk management through preparedness planning at different spatial scales has been demonstrated in numerous countries, including Brazil, Mexico, and Spain (see Box 4.2), as well as Morocco, which have focused in part on activities at the river basin level, as well as in the United States and India, where drought risk management efforts have occurred largely at the state level.[43]

[43] For examples, see Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), *Drought in Australia: Context, Policy, and Management*, Department of Agriculture, Fisheries, and Forestry (Government of Australia, March 2012); A. Turner, S. White, J. Chong, J., M. A. Dickinson, H. Cooley, and K. Donnelly, *Managing Drought: Learning from Australia* (prepared by the Alliance for Water Efficiency, the Institute for Sustainable Futures, University of Technology Sydney and the Pacific Institute for the Metropolitan Water District of Southern California, the San Francisco Public Utilities Commission and the Water Research Foundation, 2016); Brij Mohan Singh Rathore, Ridhima Sud, Vivek Saxena, Laxman Singh Rathore, Tilok Singh Rathore, Venkata Godavarth Subrahmanyan, and Murari Mohan Roy, *Drought Conditions and Management Strategies in India* (final draft of a paper available on the Internet whose actual publication and date [post-2012] is unknown); Elisa Vargas, *Drought Management in Spain* (Directorate General for Water, Ministry of Environment and Rural and Marine Affairs, Zaragoza, Spain, July 8, 2008); Public Policy Institute of California (PPIC), *Policy Priorities for Managing Drought*; WMO and GWP, and De Nys, Engle, and Magalhães (eds.), 2017.

BOX 4.1 The Drought Monitor in the United States

A key monitoring instrument was developed as the result of a partnership between National Drought Mitigation Center (NDMC) at the University of Nebraska Lincoln, the National Oceanic and Atmospheric Administration (NOAA), and the United States Department of Agriculture (USDA) with the purpose of improving and disseminating drought-related information on a real-time basis. This takes the form of the United States Drought Monitor (USDM) map, which is updated weekly, thereby raising awareness about drought conditions and impacts throughout the country. This map is used by federal and state governments to assess the evolution of drought conditions and trigger drought response and mitigation programs. It also permits early warning, improved seasonal forecasts, and delivery of this information to decision makers at all levels and to other public and private stakeholders, including individual farmers and ranchers. In short, it is an essential decision support tool for both planning and response to droughts of varying spatial incidence, degrees of severity, and duration.

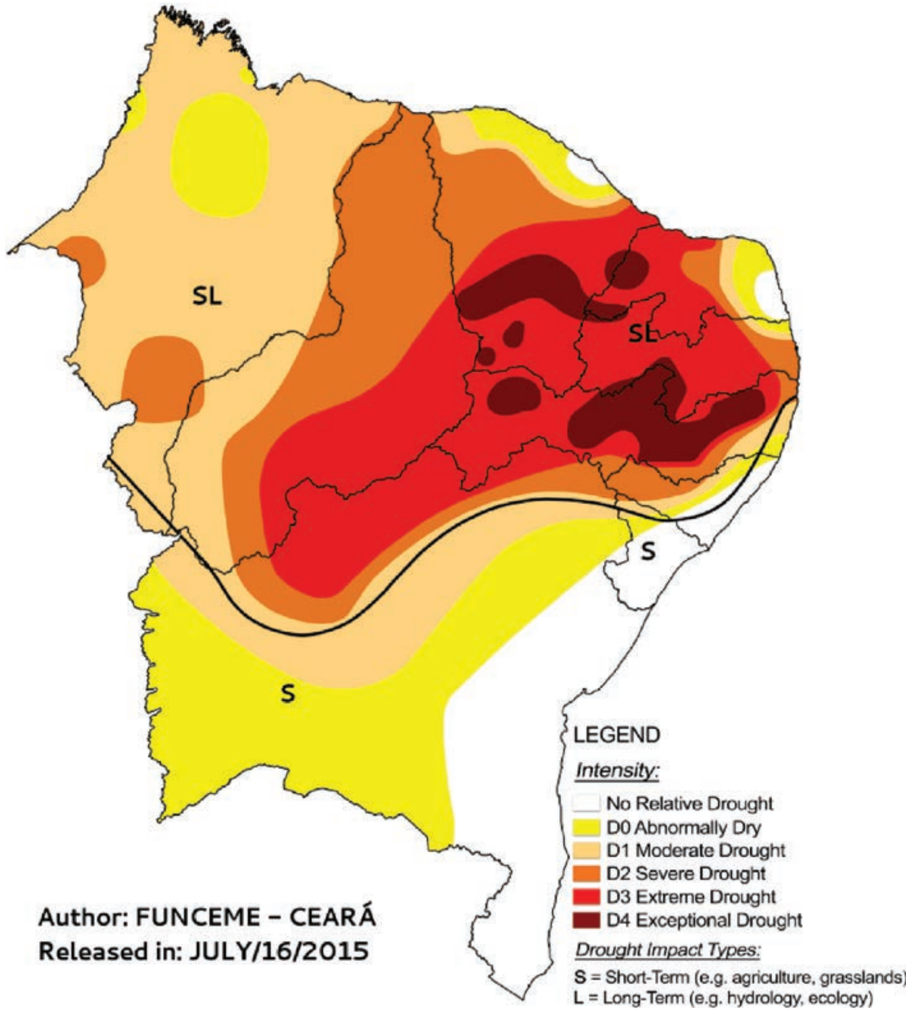
The USDM map can be readily accessed online and, based on real time monitoring data, indicates those parts of the country in drought conditions of increasing intensity, ranging from "abnormally dry" to "exceptional drought" passing through " moderate," "severe," and "extreme" drought. It also indicates whether the existing drought is short-term (that is, typically less than six months) or long-term (more than six months). The greatest impacts of the former are mainly on agriculture and grasslands, whereas those of the latter also influence hydrology and the ecological situation in affected areas. The map can be viewed on a regional, state-by-state, and nationwide basis. A short text summary that accompanies the map describes changes in drought conditions that have occurred over the previous week. It also summarizes short-term temperature and rainfall forecast information on a regional basis.

Source: Redwood 2017.

At the national level, Australia has adopted a variety of measures to help address drought impacts on the agricultural sector (see Box 4.3).

- In robust systems, better drought monitoring tends to lead to better planning over time as improved information enters the decision-making process at the national and subnational levels. This has been recognized by virtually all of the countries surveyed, both inside and outside the MENA region, although achievements to date have been mixed.
- In some countries, such as Mexico, development of a national drought policy has provided the momentum to help break initial inertial attitudes within the national government, illustrating the importance of having strong "top-down" support for drought risk management.
- Active stakeholder engagement, transparency, and broad dissemination and other public awareness and educational measures concerning drought risk, together with associated management activities, help to ensure success of these management activities.
- Continuous engagement on the part of drought-prone countries with international experience and exchange of information on drought risk management through conferences, workshops, and by other means has been beneficial both for the development of more dynamic risk management approaches and the infusion of updated knowledge and research findings into these approaches. Current technical cooperation activities in MENA, including that by ICBA and the University of Nebraska Lincoln, to support a Regional Drought Management

FIGURE 4.1 Drought Monitor for Northeast Brazil, July 2015



Source: De Nys, Engle, and Magalhães (eds), 2017.

TABLE 4.1 Drought Categories and Associated Impacts that Are Tracked Using the Northeast Brazil Drought Monitor

Category	Percentile	Description	Possible Impacts
D0	30	Abnormally dry	Going into drought: short-term dryness slows planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered
D1	20	Moderate drought	Some damage to crops, pastures; streams, reservoirs, or wells low; some water shortages developing or imminent; voluntary water-use restrictions requested
D2	10	Severe drought	Crop or pasture losses likely; water shortages common; water restrictions imposed
D3	5	Extreme drought	Major crop/pasture losses; widespread water shortages or restrictions
D4	2	Exceptional drought	Exceptional and widespread crop/pasture losses; shortage of water in reservoirs, streams, and wells creating water emergencies

Source: De Nys, Engle, and Magalhães 2017.

BOX 4.2 Drought Management at the River Basin Level in Spain and Mexico

Concrete examples of drought management in Spain can be taken from the experience of individual river basins. For instance, the Jucar River, which flows into the Mediterranean, and its basin are managed by the Jucar District Partnership or Hydrographic Confederation (CHJ), which oversees an area of nearly 43,000 square kilometers, including several adjacent basins. Development of the Jucar Basin Plan depended on the use of models and decision support systems (DSSs) for the past three decades. Special drought preparedness plans were also developed. These included definition of long-term (planning), medium-term (alert), and short-term (emergency and mitigation) measures, which are activated by the use of Standardized Operative Drought Monitoring Indicators (SODMI) for precipitation, reservoir storage, groundwater levels, and river flows obtained from an automatic data acquisition system. The SODMI and resulting threshold curves for assessment of local drought conditions are calibrated by intensive use of DSSs for drought-risk estimation, and the DSSs are also regularly used for real-time management at board meetings to assess drought risks over short- and medium-term time horizons, ranging from a few months to an entire hydrological year (extending from October to the following September), or even two hydrological years.

As a result of a severe multiyear drought, in January 2013 the Government of Mexico announced a National Program Against the Drought (PRONACOSE) to be coordinated by the National Water Commission (CONAGUA) with the assistance of the Mexican Institute of Water Technology (IMTA). PRONACOSE's basic objective is to develop tools for proactive and preventive integrated drought management (IDM) at the river basin level, following an approach generally similar to that previously adopted in Spain. Its specific objectives are to: (i) initiate a targeted training program on the basic concepts of drought and best practices to develop local capacity to ensure the sustainability of IDM in Mexico; (ii) raise awareness at the basin level and develop a host of preventive and mitigation measures against droughts; (iii) establish an interagency committee to coordinate and direct existing drought-related programs, guide and assist PRONACOSE, and fund actions proposed by stakeholders at the basin level; (iv) involve experts and researchers in responding to the identified needs of IDM; and (v) develop a communication and outreach program that emphasizes vulnerability, participation, prevention, and the evolution of drought. The program also contains an important evaluation mechanism with the aims of assessing the effectiveness of each of its implemented strategies and activities and providing continuous feedback and lessons learned to ensure its improvement over time and long-term sustainability.

Source: De Nys, Engle, and Magalhães 2017.

System (RDMS),[44] which has also generated important inputs for the current study, are being pursued in the hope of capitalizing on such exchanges at the regional level and producing positive results.

- Achieving the transition to more proactive drought policy and management extends beyond better drought preparedness and response in the agricultural sector and elsewhere and can help countries and the affected regions within them to build greater resilience to the increasing

[44] Four MENA nations – Jordan, Lebanon, Morocco, and Tunisia – are the initial beneficiaries of three-year regional technical assistance project funded by the United States Agency for International Development (USAID) and FAO, which is being implemented by ICBA and the National Drought Mitigation Center (NDMC) and the Daugherty Water for Food Institute at the UNL. The stated objective is to empower decision makers to plan for and manage the impacts of droughts on food and water security under current and future climate conditions (USAID, ICBA). This project has four major activities: (i) engaging stakeholders : needs and opportunities analysis ; (ii) establishing and operationalizing a drought monitoring, early warning and information delivery system; (iii) conducting drought vulnerability and impact assessments and developing management plans; and (iv) operational support and training for drought monitoring and early warning system. Other partners in this exercise are the FAO's regional office for the Near East and North Africa and NOAA.

BOX 4.3 Selected Drought Assistance Measures for the Agricultural Sector in Australia

Farm Management Deposits (FMDs): These are a financial risk management tool to help farmers smooth the uneven income streams in agriculture that result from market and climate variability, including droughts. This mechanism encourages farmers to set aside pretax income in good years for use in low-income years. The deposits provide tax benefits if kept for at least 12 months. Eligible farmers in areas of "Exceptional Circumstances" may access their FMDs within 12 months while retaining their tax benefits. The ceiling on deposits is US$400,000, and eligibility requirements determine if and when deposits can be withdrawn.

Tax Relief: The Australian Tax Office can help drought-affected people by: (i) allowing more time to pay tax obligations without incurring interest charges; and (ii) arranging for tax debts to be paid in installments without interest charges. In special circumstances, the Commissioner of Taxation may release individuals from normal income tax obligations on a case-by-case basis when it is demonstrated that payment would result in serious hardship. Other taxation-related measures and concessions available to drought-affected farmers include profit from the forced disposal or death of livestock and deductions for investments in water supply facilities and natural resource conservation.

Rural Financial Counseling: The national Rural Financial Counselling Service (RFCS) provides free and confidential financial counseling to farmers, fishermen, and agriculture-dependent small businesses. Although not limited to drought-related assistance, the RFCS seeks to provide information and support to rural Australians for improved access to needed services.

Social and Emotional Counseling: People experiencing stress or personal difficulties as the result of a drought can contact a counselor who will provide free guidance and support through the Family Relationship Services Program or the Drought Assistance Hotline.

Whole-Farm Planning: The adoption of whole-farm or property management is a vehicle to promote improved risk management, productivity growth, and sustainable development. Through the use of tools, such as land capability assessments, farm budgets, marketing plans, and DSSs, farm plans allow producers to identify the element of risk to their operations, including droughts, and take steps to minimize their potential impacts.

Other Instruments: Education and training that can be provided for risk management and drought-related research includes whole-farm management systems that integrate climate prediction; technical, biological, and financial information; and other pertinent developments aimed at meeting the needs of farm families in times of drought and other forms of climate stress.

Source: Australian Bureau of Agricultural and Resource Economics and Sciences *Integrated Drought Management Programme*, Canberra, 2012

climate stresses that are likely to occur in the decades ahead. Thus, droughts and the ways in which they are managed can also be viewed as "adaptation catalysts" for improving management of climate change more generally, particularly in arid and semiarid parts of the world. Recent World Bank–sponsored studies on confronting and managing droughts in the dry-land areas of northeast Brazil and sub-Saharan Africa clearly bring out this important connection (Cervigni and Morris 2016; De Nys, Engle, and Magalhães 2017).

- Successful drought risk management often requires both long-term structural, policy, and institutional interventions (such as water-related infrastructure development and ongoing water resource management and agricultural technology improvements, including those aimed at using scarce water supplies more efficiently and productively), and short-term emergency assistance measures to protect the livelihoods and ensure the protection of drought-affected

BOX 4.4 Recent Drought Management Measures in California

California has the most variable rainfall in the United States with a few large storms making the difference between a wet and a dry year, and the recent multiyear drought significantly reduced the amount of water held in the state's reservoirs. This led to severe water shortages and a 50 percent reduction in hydropower generation in the state. In response, the governor declared a statewide drought emergency and established an interagency drought task force in 2014. Both the state and federal governments have provided funding for drought relief, and the state water control board, which is responsible for administering water rights and quality standards, has approved water allocation plans that curtailed water diversions for many lower priority water users.

Some of these measures directly affect the state's agricultural sector, which requires a high volume of water for irrigation during the dry summer months. This amount is estimated to be four times more than that required by the state's populous cities, even during years of normal rainfall. Over the past few decades, farmers have reportedly adapted to the growing water scarcity by making significant investments in more efficient irrigation systems and shifting production to higher value crops per unit of water used. But these changes reportedly did not adequately increase resilience to drought or sufficiently augment overall water supply. Thus, in 2014, new state legislation was enacted, including the Sustainable Groundwater Management Act, and a US$75 million new water bond was approved. In January 2016, the water control board adopted a resolution authorizing the sale of an additional US$1.2 billion in revenue bonds for the Clean Water State Revolving Fund to meet further financing needs for new water infrastructure projects.

Source: Redwood 2017.

families and communities, especially in the most vulnerable rural areas. This approach has recently been recommended by the World Bank for application in northeast Brazil but is applicable to other drought-affected parts of the world as well.

- Effective drought management likewise requires both supply-side (that is, expansion of water availability for both human consumption and more sustainable agricultural and livestock production) and demand-side measures, including sectoral water use prioritization and usage restrictions, as well as pricing and incentive programs, primarily aimed at conserving water and allocating it to priority uses during drought-related periods of increasing water shortage. This is being applied to help combat droughts in places as different as Australia (Box 4.3), California (Box 4.4), and, in the MENA region, Morocco.[45]
- Policy and institutional coordination, together with that of drought monitoring, mitigation, and response activities, among different levels of government and between the public and private sectors and civil society, particularly at the local level, are likewise essential. Again, many of the individual country experiences examined both in MENA and elsewhere illustrate the importance of improved communication, coordination, and collaboration among governmental agencies and NGOs, as well as supporting participatory decision-making processes more generally.

These lessons are particularly important for the agricultural sector (including livestock) and the populations that are dependent on it for their subsistence and livelihoods. This sector is particularly

[45] See World Bank, *Climate Variability, Drought, and Drought Management for the Agricultural Sector in Morocco*, (Washington D.C., 2017).

vulnerable to droughts and especially to those that last for more than one planting and harvest year. Moreover, some of these populations live in relatively remote and, thus, harder to reach locations, which also makes it more difficult and costly to provide drought relief assistance to them. The evolution of the Tunisian government's approach to drought management over the past four decades further illustrates the relevance of many of the lessons mentioned.

4.3 EVOLUTION OF NATIONAL DROUGHT POLICY, PLANNING, AND INTERVENTIONS IN TUNISIA

As indicated in the two preceding chapters, during the 20th and early 21st centuries, Tunisia experienced a number of severe droughts, which occurred on average once every 10 years. Both the end of the 1980s and the beginning of the past decade, for example, were characterized by the occurrence of intense droughts and high rainfall deficits. In addition, because of Tunisia's geographic location, which puts it in direct contact with two different climate regimes—a wet temperate zone in the north adjacent to the Mediterranean Sea and a dry tropical one in the south near the Sahara Desert—there have been significant differences in drought frequency and intensity, as well as climate variability more generally across the national territory. Rainfall levels are significantly higher in the north than in the south, varying from an annual average as high as 359 mm in the north region to as low as 11 mm in the south. According to a recent study on drought conditions and management strategies in the country by representatives of the former Ministry of Agriculture and Water Resources (MARH), which is now called the Ministry of Agriculture, Water Resources, and Fisheries (MoAWRF), and the National Meteorology Institute (INM), "frequency of two consecutive dry years and more is relatively low in the North, moderate in the Center and more frequent in the South," whereas "drought periods could affect one or several regions or could be generalized, their duration could be from one month or season to one year or more" (Safouene and Lofti, p. 3).[46]

Despite these differences, Tunisia, like other countries in the MENA region, has scarce freshwater, and the vast majority of its water use (80 percent) is for purposes of agricultural irrigation (Horchani 2007), with less than one-fifth consumed by domestic, municipal, industrial, and other sources. Thus, as previous chapters have shown, periodic droughts have a strong impact on the agricultural sector, particularly in the northern part of the country where cereal (wheat and barley) production is largely concentrated. According to MoAWRF, for example, during 1987–88, 1993–94, and 1996–97, all of which were dry years, deficits in cereal output compared to the average were 77 percent in the north and 93 percent in the central parts of the country (Safouene and Lofti). These crops are critical for internal food security and as a source of fodder for livestock, so drought-related domestic shortages lead directly to the need for increased imports, often at higher prices. Other significant droughts were experienced in 2000–02, which was particularly serious given its multiyear nature, 2010 and 2015–16, during which noteworthy cereal and other agricultural output declines were also recorded.

[46] Although not specifically addressing drought management, an earlier paper by Mohamed El Hedi Louati of MARH, in collaboration with Julia Bucknall of the World Bank, entitled *Tunisia's Experience in Water Resource Mobilization and Management,* was drafted as a background paper for the World Bank's 2010 World Development Report (WDR) on Development and Climate Change and provides a useful overview of activities in this regard.

Until the mid-1990s there was little systematic drought management in place in Tunisia despite the severe droughts experienced in the 1980s. Public Law 91-39 on the designation of a Permanent National Calamities Committee related only to floods, with no actions put into place for managing droughts. The first official reactions came with the successive droughts of 1994–95 (Decrees 94-1588 and 95-1096) and 1997 (Decree 97-1807), when the government declared officially as drought those areas experiencing crop failures. The main actions of these government decrees was credit rescheduling for farmers in the areas delineated as affected by drought. However, this did little for smallholders because they did not have access to credit. A 1999 Practical Guide to Drought Management provides information about monitoring indicators but has not been widely used or implemented because there is little to connect physical condition monitoring with concrete management actions (Jlassi 2016).

Drought Monitoring and Early Warning. To monitor weather and water-related conditions, INM and the MoAWRF's General Directorate of Water Resources (DGRE) maintain monitoring stations throughout the country to measure precipitation, temperature, river flow, and groundwater levels. Various indexes based on these data are elaborated and disseminated to stakeholders. The density of these national monitoring networks, particularly those to measure river flows, is much higher in the north and center, which account for most of Tunisia's agricultural production (especially in the area around Tunis for rainfall measurement and in the north for river flows). This also reflects the considerable differences in surface and groundwater availability across subregions in that 60 percent of the country's water resources are concentrated in the north, in roughly 17 percent of the national territory, compared with 18 percent of such resources in the center and 22 percent in the south, which account for 32 percent and 51 percent of the country's land area, respectively.[47] The rainfall measurement network consists of 850 stations and 100 pluviographs. Statistics have been collected since 1969, and the data are published on a daily and monthly basis. The flow monitoring network consists of 60 stations and 74 measurement points, and its statistics have been presented since 1974–75 (Nouiri, Nasri, and Tahrani 2014).

Drought Risk Management. Based on these data and an analysis of the historical patterns of rainfall incidence in various parts of the country, a national drought risk map was developed. In addition, between 2006 and 2009, the SMAS (Maghreb drought early warning system) regional project, financed by the European Union, was carried out by the Sahara and Sahel Observatory (OSS). This system also covered Algeria and Morocco and had the objective of helping to prevent environmental degradation caused by droughts through development of adaptation strategies to reduce the impacts of drought through employment of an early warning system. The system entailed the production and dissemination of natural resource vulnerability indicators based on climate, biophysical, and socioeconomic data together with the use of satellite imagery. The study, which involved close collaboration among the three national meteorological institutes, also included climatic zoning and validation of a climate-related index, the SPI, which was likewise used by other countries for drought monitoring purposes. Its results were synthesized in a drought bulletin.

Tunisia's Water Code, first adopted in 1975 and periodically updated since, covers drought-related actions, among other elements. The Code stresses the need for improvements in the efficiency of water use in all sectors and gives priority to securing drinking water supply. It contains specific measures to

[47] Similarly, the North possessed 81 percent of Tunisia's surface water, compared with 12 percent in the Center, and 7 percent in the South.

economize on water use in agriculture, including the provision of grants, ranging from 40 to 60 percent of farmers' investments for water-saving irrigation practices. During drought periods, the Central Bank is also able to ease credit conditions for farmers and authorize exemptions from customs duties.

According to local sources, Tunisia has put a national drought management system in place in response to recurring drought events in the 1980s, 1990s, and 2000s. In 1999, the government published its first guidelines on drought management: *Guide Pratique de la Gestion de la Sécheresse en Tunisie* (the *Practical Guide to Drought Management in Tunisia*). These guidelines outlined methodological approaches, identified the principal drought indices, and described drought preparedness and management processes. The MoAWRF/INM paper referred to previously stated that Tunisia's current drought management system has "three successive steps":

- **Drought announcement:** Such an announcement is based on meteorological, hydrological, and agricultural indicators as observed in different regions affected by the drought and transmitted by the agricultural, economic, and hydrological districts of relevance for agriculture and water resources as determined by MoAWRF. The drought announcement takes the form of an official decree that is published in the official journal of the Tunisian Republic. This decree includes the list of affected localities and the drought severity levels, as well as decisions related to subsidies and rescheduling of credit payments if necessary.
- **Warning:** This announcement is transmitted to the Ministry of Agriculture, Water Resources, and Fisheries, which proposes an operational plan to a national commission composed of decision makers and beneficiaries. During the drought, intervention programs are activated based on an assessment by the Ministry's technical services regarding water and agricultural resource status, including reservoir levels and seed and feed stocks. Subsequent measures are implemented according to five different scenarios based on the evolution of the drought in progress. These scenarios and the measures taken under each are summarized in Box 4.5.
- **Action implementation:** The aforementioned national commission is responsible for overseeing implementation of the measures contained in the operational plan in collaboration with regional and other specialized committees.[48] This commission also oversees any postdrought activities (Safouene and Lofti, 2014).

In short, MoAWRF officially declares droughts in Tunisia. The technical services of this ministry assess the drought situation at the start of the agricultural season based on three main indicators:

- Rainfall: Lack of significant summer breaking rainfalls (August–October) and rainy season precipitation deficit higher than 40 percent;
- Water reservoirs: significant depletion rate of dams; and
- Agricultural status: affected pastures, dehydration of olives, delayed farmers practices related to soil tillage, and inflation in feed prices.

[48] According to Nouiri, Nasri, and Tahrani (2014), there are 24 regional commissions (one for each governorate) and four specialized regional ones, for water resource management, livestock safeguard, cereal sector management, and arboriculture sector, respectively.

BOX 4.5 Drought Scenarios Considered for Decision Making in Tunisia

Scenario 1: If autumn is dry (rainfall deficit higher than 40 percent), the probabilities that the season is dry in the north and the center-south regions are 80 and 90 percent, respectively. Monitoring focuses mainly on cereals-based systems in the center-south and fodder-based systems in the north. Preventive measures are:

- identifying affected areas and providing smallholders with barley seeds and straw;
- reinforcing irrigated cereals in the center;
- assessing feed stocks and planning feed import for mid-November; and
- preparing dam water management plans according to future evolution of the climatic condition.

Scenario 2: If the winter is dry in the north (its contribution is about 41 percent of total rainfall), preventative measures are:

- identifying affected areas for targeting interventions;
- assessing dam levels to judge which plan to opt for;
- inciting irrigators for supplementary irrigating seed production end-purpose plots; and
- predicting needs for import of basic commodities according to the evolution of the climatic conditions.

Scenario 3: If the spring is dry, preventative measures are:

- reinforcing cereals supplementary irrigation to ensure minimum production as identified in the national strategy;
- assessing pasture status to cover feed deficits;
- assessing cereals productivity to stop importation program; and
- assessing water stocks and allocations for different usages.

Scenario 4: If the first year is dry (40 percent rainfall deficit), the probability that the following year is dry is from 7 to 23 percent and from 25 to 30 percent in the north and center, respectively. Water resources are significantly depleted and agricultural and pastoral systems are affected. Drinking water is lacking in sensitive areas, and animal diseases are dispersed. Preventative measures include:

- determining feed deficit and planning vaccination campaign for drought-related animal diseases;
- stopping the plan of dam water allocation, which is done to prevent depletion in the situation of consecutive dry years; and
- preparing for the coming season: credits, soil tillage, and seed distribution.

Scenario 5: For a consecutive dry year, preventative measures include:

- careful water facilities management;
- reinforcing groundwater pumping from official ministry wells;
- reinforcing measures taken in year 1 in relation to potable water in rural vulnerable areas;
- limiting irrigated parameters for staples crop production and for less-water-consuming crops;
- encouraging use of treated wastewater for fodder irrigation;
- employing media communications about optimal water usage for all sectors;
- importing feed and subsidizing the prices (subsidies are funded by taxes on meat import); and
- controlling feed speculations to limit inflation.

Since 1990, drought has been officially declared in 1994, 1995, 1997, 2000, 2001, 2002, 2008, 2010, 2013, and 2016. The most severe drought in 50 years was over three consecutive years from 2000 to 2002 (Decrees 2000-1881, 2001-2110, 2002-1699), with government interventions costing an estimated US$54 million. These interventions covered many areas, such as vaccinations of livestock, providing feeding blocks to smallholder farmers and herders, and subsidizing hay prices and attribution of yearly basis credits (Louati 2005).

Beyond the official drought definition used in Tunisia, in a recent survey about droughts and their management,[49] stakeholders described a wide range of indicators and impacts they used that were specific to a locale and a given field of activity. For example, stakeholders in Kairouan described the level of certain sabkha (inland salt flats) as an excellent indicator of drought intensity in the relevant groundwater basin. In Kasserine and Kef, stakeholders said the chemical characteristics and discharge volumes of certain natural groundwater springs reflected drought conditions in their localities. Beyond these immediate indicators, stakeholders mentioned a wide range of other factors that indicate drought, of which the following are selective examples:

- Bird migration patterns in the fall and spring;
- Bee honey reserve volume and quality;
- Delay of trees' winter dormancy (especially almonds) and timing of flowering;
- Farmers opening cereal fields (especially wheat and barley) for livestock grazing;
- Presence and intensity of certain tree pest infestations, especially for forest plantations; and
- Low olive pollination during spring and signs of tree dehydration.

An alternative description of Tunisia's drought management system also identifies three stages, although these are somewhat more comprehensive. According to this source, each of these stages involves the following activities:

- **Drought preparedness:** (i) climate and hydrological data are analyzed to predict the hydroclimatic situation; (ii) a water management program is established; (iii) provision of water point equipment for domestic use when the drought sets in; and (iv) the national program of water saving is enhanced by raising public awareness about the emerging drought event.
- **Drought management:** (i) identification of the affected regions; (ii) evaluation of dams and water reserves and adjustment of the management plan in accordance with the available water supplies; (iii) enhancement of the irrigated cereal program; (iv) encouragement of complementary cereal irrigation, especially in seed production areas; (v) evaluation of animal nutrition stocks and forecasting of potential associated import requirements; (vi) supplying drought-affected areas with barley and other fodder as needed; and (vii) identification of other priority products to be imported.
- **Postdrought:** (i) intensification of extension programs related to soil tillage and water-conserving farming practices; (ii) establishment of a scheme for deferring credit payments; (iii) programming the distribution of cereal and forage seeds; (iv) evaluation of the available

[49] ICBA and NDMC (National Drought Mitigation Center) University of Nebraska, Lincoln (UNL) under a USAID-funded project, undertook a survey of more than 50 stakeholders from government agencies, the private sector, civil society organizations, and research institutes on droughts and their management in Tunisia from February to May 2016.

water resources (reservoirs and aquifers); (v) reconstitution of aquifer reserves; (vi) evaluation of mitigation program efficiency and costs; (vii) updating of the drought mitigation program and incorporation of measures to address any identified shortcomings; and (viii) engaging research institutes and universities in development of a research program related to drought mitigation (Nouiri, Nasri, and Tahrani 2014).

In the postdrought phase, more specifically, government measures focus on ensuring that the benefits from more favorable agricultural seasons are maximized. Seasonal credits created for smallholder farmers support their investments that increase production, and seed distribution programs are activated to ensure farmers are able to cultivate all areas even when their seed stocks are low from preceding conditions. Artificial groundwater recharge is activated, and pumping from overexploited drinking end-use purpose aquifers is stopped. There are also attempts to quantify the financial impacts, evaluate interventions plans, and determine weaknesses. Finally, there are moves to support research institutions in specific study areas related to crop and animal breeding needs highlighted by the drought.

Civil society stakeholders described a decrease in drought interventions over the past 15 years and a deterioration in interventions' effectiveness. They said that interventions during the 2000–02 drought were far more decisive, rapid, and effective than any that have come since. They also stated that the effectiveness of measures was attributable to the rapidity with which they were implemented and the accountability of officers responsible for them. Stakeholders described drought management and intervention issues in relation to distinct themes:

- **Surface water management**: Civil society stakeholders stressed the need for increased transparency from government agencies in surface water infrastructure management and clear publication of decision making of allocation and priorities during periods of drought. Irrigators and stakeholders outside the agriculture sector said they do not have access to water infrastructure operation rules, available information about storage levels is ambiguous, and anticipating the amount of surface water available for utilization is difficult because decisions are not published regularly or disseminated effectively.
- **Groundwater management**: Both government and civil society stakeholders stressed the importance of proper enforcement and respect of groundwater well regulations, especially during droughts. Often the response of some water users is to drill illegal wells to augment their flows during these times. For example, civil society stakeholders in Kairouan and Kasserine estimated that two to three times as many illegal wells exist as legal wells. They stated the problem predates the revolution but has increased enormously since. Government and civil society stakeholders acknowledge problems in the well-permitting process and state that groundwater usage conflicts have increased enormously because of drawdown, especially during droughts.
- **Agricultural interventions:** Stakeholders said that direct government-funded drought interventions in agriculture in 2016 focused on tree crops and fodder provision.
- **Tree crops:** Stakeholders in Sidi Bouzid, Kairouan, and Kasserine described this year's point-irrigation drought intervention campaign for olives and tree crops as arriving far too late. In many cases, tree crop farmers without irrigation infrastructure were forced to purchase water from illegal private vendors, often at prices well over 10 times higher than typical irrigation water, or let their trees dry.

- **Fodder provision:** Fodder crop prices more than doubled this year in relation to typical seasonal price changes, and in many markets fodder crops were almost completely unavailable for significant periods. Civil society stakeholders said the government had poor control and oversight over speculation and began fodder provision campaigns too late to alleviate market prices and avoid negative impacts on livestock.
- **Strategic planning:** Both civil society and state government stakeholders described strategic, top-down decisions as generally arriving far too late generally, including in 2016. In a given drought season, tactical planning is occurring too late for it to have strategic importance. The archetypical example stakeholders provided related to crop planning in public irrigation perimeters (PPI, in the French acronym). During drought years, PPI authorities ban cultivation of certain crops and reduce cultivable area for others. This year farmers were instructed to wait for planning directives. However, these directives did not arrive before the end of the crop planting period, so farmers planted without knowledge of the volumes of water that would be available. Farmers therefore faced severe losses because of inadequate water availability for their plantings.
- **Financial management**: Direct financial interventions aside from subsidies primarily include prolonging credit repayment periods or automatically issued loan increases. However, direct interventions in the agriculture-focused finance sector are difficult because the most important formal actors, government-controlled banks and insurance firms (Banque Nationale Agricole [BNA] and CTAMA (Caisse Tunisienne D'Assurance Mutuelle Agricole)) are utilized almost exclusively by large landowners and agribusinesses. Farmers and civil society stakeholders estimated that approximately 90 to 95 percent of farmers turn to agro-industry firms (for example, Delice), providers of agricultural inputs and equipment, and their own social networks for credit. Insurance products are highly limited and do not cover drought. Thus, the government has few tools to reach farmers directly for agricultural credit and catastrophe bailouts. Farmers particularly want the national catastrophe fund to be capitalized and utilized or to be able to create independently administered financial instruments for drought payouts.

Stakeholders in all drought meetings linked the rapidly changing role of the government in broader society and the vertical relationships within the government itself to discussions of drought management. These changes predate the revolution but have accelerated rapidly since 2011. The traditional role and reach of numerous government agencies is now different and often reduced considerably. Conflicts of interest, weakness in self-enforcement in the absence of government oversight, and unclear institutional relationships have accompanied the transition, making governing more difficult. Representatives from GDAs (agricultural development groups), which are cooperative groups within irrigation districts, gave as an example their own inability to enforce water payment collection as the primary cause for infrastructure deterioration in PPIs and decline in production. As a result, investments do not safeguard supplies during future droughts.

4.4 PERSISTING CHALLENGES AND GAPS

While acknowledging that, as of the time it was drafted (presumably 2014 or later), Tunisia's drought management system had not been "analyzed deeply," the MoAWRF/INM paper nonetheless identified a number of factors considered to represent the system's strengths and weaknesses. The former included

that high presidential interest and support had been devoted to the system and that it had helped to protect the sustainability of farmers' incomes. It had also contributed to "integrated and optimized" water resource management in the country during drought periods, although this varied in accordance with the intensity and duration of the droughts. The paper also emphasized that water saving was a national policy domain and not just a concern during drought events.

The drought management system also possessed several weaknesses. One was that the financial resources utilized to respond to droughts had to come largely from the central government's budget due to the absence of insurance mechanisms and only limited private sector contributions. A second deficiency was that, until 2003 at least, drought mitigation plans were based on "simple note-taking and observation findings, without any widespread evaluation study," although apparently this weakness was expected to be addressed as part of an "in-process study" regarding the impact of climate change on ecosystems and the agricultural sector. In any case, there was a need to update these plans.

Institutional communication difficulties were also identified as a weakness, particularly with respect to "information and data about water." However, it was expected that establishment of the Unified National Water Resources Information System (SINEAU, for Systéme d'Information National des Resources en Eau) would help to resolve the problem in the near future. This notwithstanding, different parts of MoAWRF, the Ministry of Environment, and other ministries and agencies at the national, regional, and local levels are involved in various aspects of water resource and drought management in Tunisia (Safouene and Lofti, 2014), so interinstitutional coordination is likely to be a persisting issue.

Another key weakness is the need for greater knowledge and skills regarding drought management and, thus, for greater national institutional capacity for drought policy and planning. This includes needs for development of: (i) more reliable forecasts and indicators; (ii) comprehensive early warning systems; (iii) drought preparedness plans at all levels of government; (iv) mitigation policies and programs to help reduce drought impacts; and (v) a coordinated emergency response program that ensures timely and targeted relief during drought events (Safouene and Lofti, 2014). In addition, a number of supply- and demand-side water scarcity and drought management instruments used in Jordan, Morocco, Palestine, and Tunisia found that Tunisia compared unfavorably with the other MENA countries considered, particularly with regard to demand-side management, as Table 4.2 indicates.

Those who have studied droughts and drought management activities in Tunisia recognize that such events are likely to become more frequent and serious in the future based on the results of existing climate change models. Thus, although they consider that Tunisia currently possesses both a monitoring system for identifying the onset of drought events and an institutional framework to address them when they occur, there are still a number of key areas where improvements are needed. These include better definition of drought indicators and indices, elaboration of a legal manual to use when a drought is declared, strengthening of information processing and sharing mechanisms, and greater use of modeling and optimization tools to inform decision making (Nouiri, Nasri, and Tahrani 2014).

In the survey of stakeholders by ICBA/UNL in 2016, there were different reactions to the drought management system currently in place, but government and civil society stakeholders shared several important perceptions about existing drought management strategies and interventions. First, they agreed that the types of drought interventions, at least in relation to agriculture, have not changed drastically in recent years and should not. In addition, stakeholders at the national and state levels were unanimous in their agreement about the need to improve drought decision-making processes.

TABLE 4.2 Comparative Use of Supply and Demand Side Water Scarcity and Drought Management Instruments in Selected Countries in the Middle East and North Africa

Instrument/Country	Jordan	Morocco	Palestine	Tunisia
Water storage	X	X	X	X
Use of marginal groundwater	X	X	X	X
Aquifer recharge	X	X	X	X
Improved network efficiency		X	X	X
Relaxing environmental constraints	X		No	X
Water transfers	X	X	X	X
Desalination	X	X	X	X
Wastewater reuse	X	X	X	X
Water metering	X	X	X	X
Mandatory rationing	X	X	X	X
Restriction on municipal use	X	X	X	No
Water markets (tariffs and cost recovery)		X	X	No
Water-saving campaigns	X	X	X	X
Awareness campaigns	X	X	X	X
Increased irrigation regulation	X	X	X	X
Increased urban water supply regulation	X	X	X	No

Sources: United Nations Department of Economic and Social Affairs (UNDESA) and University of North Carolina (UNC) Charlotte.

Farmers and civil society stakeholders described the delay in government decisions about drought management planning and poor communication of such decisions as the greatest weakness in the existing system. State government stakeholders stressed that information feeds up to the central administration effectively but that strategic planning and decisions frequently arrive after the relevant event or negative impacts have occurred.

Local stakeholders interviewed by ICBA/UNL indicated, in short, that the government's response to drought conditions has often been too little and/or too late. These observers argue that "two steps—setting up drought monitoring and revising the current drought plans—are required in the short term so that more clear and practical actions including water allocation priorities can be implemented quickly and effectively once the onset of drought is identified." In addition, they affirm that, over the longer run, there is a need to acknowledge that drought has been and will continue to be an important influence on the Tunisian economy and people, and there is a need to undertake sector- or community-based vulnerability and risk assessments so that resources can be targeted more effectively.

According to these sources, this might also require rethinking crop selection, planting patterns, and food storage systems; managing water resources and associated infrastructure more efficiently; and building systems that directly respond to conditions so that decisions can be made before the impacts have taken effect. There is also a need to include drought insurance, such as that existing in

Morocco, and a fund for natural calamity relief that includes drought because not all conditions can be mitigated through practical water and crop solutions alone. Within any preparedness plan, moreover, there should be sets of actions based on the state of the drought, including specifying the measures to be taken both by water utilities and farmers.

For drought management, the desired structure of government institutions' roles in drought monitoring and management is now generally clear in concept. However, government stakeholders said that, in practice, the roles and responsibilities of each agency become blurred because of the number of directorates involved and, at times, because of their competing interests. Beyond this, many government stakeholders said they were not sure of the actual mechanisms of political decision making regarding drought interventions. Decision making appeared to occur in an opaque fashion and was dependent on the securing of financial resources beyond the planned budget. This is complicated by the increasing turnover in government staff with the associated loss of institutional memory and breakdown of established personal networks that were important in the past for actions to be implemented.

As a result of these issues, stakeholders in state government and civil society and some national-level government stakeholders described the current top-down drought decision-making model as highly inefficient because of the lag time between local assessment of drought impacts and beginning of government-led drought interventions. Nearly all government and civil society stakeholders, as well as some national government stakeholders, suggested that decentralization of certain budgetary and administrative powers would permit faster, more flexible interventions that could be tailored to local needs. This would reduce the time and political complexity of negotiations needed at the national level.

Against this changing public sector background, stakeholders described the rapid proliferation and reach in civil society organizations aiming to advance farmers' interests and development, such as agricultural management firms, and the expanding role of farmers' unions. They are beginning to fill the gap left by the loss of farmer extension services with the receding role of the government. Stakeholders also cited the expanding role of the private sector in key agricultural market chains, especially wheat and fodder crops, and the influence they are having on drought preparedness.

Civil society stakeholders expressed the desire to formalize these new roles to cement the links they have forged between farmers and the government as well as to exert authority and enforce government accountability. These organizations could play an enhanced role in drought mitigation and management efforts, especially in working directly with farmers to help them develop greater resilience to these extreme events. One critical area in drought management is monitoring using a drought definition that is acceptable by all key authorities. In most countries, regular drought maps are produced that highlight zones affected and the degree of severity of the dryness relative to normal conditions for that time of year and area. In Tunisia, a comprehensive drought monitoring system is not in place to support the various stakeholders involved in decision making and managing the impacts. In the recent survey, stakeholders highlighted the lack of available technical experience in remote sensing and/or physical modeling required for this. Some stakeholders were also highly skeptical of the accuracy of remote sensing-derived data and stressed that initial perceptions of the performance of any monitoring system are absolutely critical for uptake and use of the system.

Finally, it is important to acknowledge that ongoing technical assistance activities by ICBA, UNL, USAID, and FAO are seeking to bridge technical gaps in the current drought monitoring system in

Tunisia and three other countries in the region. As a result, prototype drought maps are being generated and validated through the use of remote sensing and modeling data for key drought indicator variables, such as SPI, soil moisture, vegetation stress, and evapotranspiration. Once fully developed, this technology will be transferred to pertinent national institutions, which will also receive training with the intention of producing calibrated, updated maps on a monthly basis to facilitate more timely and appropriate decision making and better targeted mitigation interventions. In addition, it is recommended that future drought mitigation measures in Tunisia (and elsewhere in the MENA region) be embedded within national and subnational climate change adaptation strategies, taking a more dynamic and proactive risk management strategy rather than the more traditional, reactive crisis response.

CHAPTER
FIVE

POLICY OPTIONS

As indicated in the preceding chapter, the Government of Tunisia is already taking a number of steps to address the rising frequently and severity of climate variability and change-related drought events. However, a review of recent international experience with respect to drought policy and management reveals that successful interventions in this field are increasingly based on a framework known as Integrated Drought Management Planning developed by multiple international stakeholders and led by the World Meteorological Office (WMO) and the Global Water Partnership (GWP). This risk management approach, which emphasizes drought preparedness, is predicated on the three pillars mentioned in Chapter 1: (i) drought monitoring and early warning; (ii) vulnerability and impact assessment; and, (iii) mitigation and response. Based on the findings of the present study, this report proposes a five-pronged approach to more climate-resilient drought management for Tunisia, which covers each of these three pillars, as well for drought policy, planning, and risk management more generally.

5.1 NATIONAL DROUGHT POLICY

Tunisia currently lacks a comprehensive national drought management policy or strategy even though many of the basic elements and potential instruments for its implementation are already in place. Others, however, are still lacking (see items 3–5), as is a well-defined institutional coordination mechanism. It would, thus, be useful for the Government to bring the various components of drought monitoring and management activities in Tunisia together with the purpose of developing a comprehensive policy or strategy in consultation with key public and private sector stakeholders, including at the Governorate and local levels in those sectors and geographic areas that have historically been most affected by recurring drought conditions. This process, which could be participatory in nature, could build off the country's own historical experience with drought management, but also be informed by the lessons of experience and demonstrated good practice, elsewhere in the region and internationally. The ten step process for formulation of a national drought management policy or strategy indicated in Chapter 1 (Box 1.2) could play a useful guiding role.

Development of a national drought management policy or strategy is strongly encouraged in the context of climate variability. The links between drought risk in the short run, on the one hand, and the

need to adapt to longer-term climate change, on the other, are particularly pressing. To more effectively address drought conditions in the years and decades ahead, these links need to be fully integrated into drought policy, as well as in both national and subnational strategies and management plans. Ongoing technical assistance and capacity building and regular information exchange with institutions and specialists facing similar challenges in other countries in the MENA region and elsewhere could prove to be helpful in this regard.

5.2 GENERAL APPROACH TO DROUGHT RISK PLANNING AND MANAGEMENT

Tunisia needs to more fully adopt a proactive risk management and adaptation approach rather than the reactive crisis response thinking that has generally dominated in the past. Good drought plans have been developed in the face of previous droughts, but their implementation has often proven difficult. More integrated drought monitoring coupled with practical drought mitigation planning and capacity development could help. These and other institutional capacity building and investment activities will likely take on even greater importance in the future. The main reason for this is the need for more effective mitigation planning and climate change adaptation strategies in view of the strong prospect of even more intense droughts and the increasingly serious associated rural water scarcity in the decades ahead, which are likely to affect even more sectors and communities. These elements are in place, but are not well-coordinated.

For example, Tunisian stakeholders report that technology to monitor (and therefore reduce) overdraft of groundwater supplies exists, but the situation is complicated by overdraft and saline intrusion. This problem has resulted in a need to understand this dynamic as part of groundwater management and aquifer recharge efforts. Monitoring activities under an integrated management plan can facilitate this assessment of the tradeoffs involved in groundwater use during drought. Thus, future drought risk and water resource management must go hand in hand along with planning for the agricultural sector more generally. The short-term benefits in terms of increased (authorized and unauthorized) groundwater extraction for agricultural production and livestock survival purposes during severe drought periods in Tunisia must be assessed against possible long-term costs resulting from diminished water supplies and food security over the longer term. Because of this increasingly critical trade-off, a cross-sectoral and long-term approach is required.

5.3 DROUGHT MONITORING AND EARLY WARNING

Development of a series of agreed-upon, scientifically sound, climatological drought onset indicators that reflect the nature of conditions in Tunisia could also be a priority. Once defined, these indicators could be the starting point for initiating coordination and cooperation efforts across the various agencies responsible for taking specific actions. To facilitate this, an integrated agricultural, hydrological, and meteorological data-sharing platform, which connects information from different relevant agencies and has automatic updates of specified data sets, could be established. In addition to improved drought monitoring, there is a need to better link technical and institutional efforts to

provide a simple, but technically sound, early warning system with structured mechanisms to initiate broad drought management coordination before the occurrence of major drought-related impacts.

There is also a need to reach beyond the satellite images and model outputs to the experts throughout the country who are able to identify on the ground the signs of drought in their own areas. In short, there is a need to "ground truth" the information generated by automatic data generation devices and associated modeling activities by establishing a continual two-way information exchange and validation process regarding the outputs of these mechanisms and the observations of key local human informants (such as farmers, extension agents, and other stakeholders) in each of the affected areas. The development and implementation of expert networks to provide feedback and strengthen current drought monitoring efforts and information products could greatly help mapping accuracy as well as support ownership and trust in the reliability and capacity of maps to improve drought management decision making. More local-based links and mapping could also help coordinate planning at the national and river basin levels, which is being promoted under the new water law.

Another key potential use of these generated data is as a basis for drought mitigation and climate change adaptation more generally for rural Tunisia. By linking drought maps and related data to existing seasonal to decadal forecasts and hydrological modeling systems, scenario planning and operation optimization could be undertaken to support infrastructure development and other operations to mitigate drought impacts over both the short and the long terms. This also suggests the need to more clearly link national and basin-level efforts to anticipate and respond to recurrent droughts and to adapt to the broader effects of climate change more generally in the agricultural and livestock sector in the country, including the need to better assist, through training and other means, farmers who lack the knowledge and skills to adapt effectively, as identified for the two high-value chains considered in this study.

5.4 VULNERABILITY AND IMPACT ASSESSMENTS

One other significant way to better anticipate and thus to prepare to more effectively address the impacts of future droughts is to carry out up-front vulnerability and impact assessments in the geographic areas most likely to be affected based on experience. These assessments could be undertaken at varying spatial scales, including at the river basin level, and could help form the basis for the development of localized drought preparedness plans, as has recently been demonstrated for historically drought-prone northeast Brazil, for which a regional drought monitor has been created and is fully operational; in the process, an effective platform was established for institutional cooperation and coordination involving pertinent federal, state, and municipal government agencies and specialists (for details, see De Nys, Engle, and Magalhães 2017).

More generally, the list of potential economic, social, and environmental effects of droughts listed in Chapter 1 could provide a useful starting point and analytical framework for identifying particular effects and vulnerabilities at both the national and subnational (such as province, district, and community) levels. These assessments, together with an institutional capacity analysis and identification of financing mechanisms, could form part of the inputs for the elaboration of drought preparedness plans at various levels; an example is the recent experience in Brazil, where such plans were developed on an indicative basis for the river basin and even municipal levels. In combination, these plans would be a key part of a more anticipatory and proactive approach to drought management.

5.5 DROUGHT MITIGATION AND RESPONSE

Strong institutional coordination mechanisms that clearly specify the role of each agency involved in drought management and adequate financial resources are also needed. Ideally, a single authority could be designated to lead drought management-related decision making and coordinate implementation of the agreed resulting mitigation activities. Improved information sharing and establishment of triggers to determine what types of actions need to be taken in what locations in accordance with the evolution of local drought conditions, including their extension over time and severity, could also be an essential part of this system. In short, this drought governance arrangement could establish the roles of specific partner institutions early (that is once onset of a new drought is detected through the monitoring and early warning systems mentioned). A national drought contingency fund could also be established with funds to distribute to those most at risk during drought events. The financial capital and budgetary management resources to enable the required response actions to be implemented in a timely manner need to be identified clearly and allocated in such a way as to obtain the most cost-effective results.

Greater timeliness and transparency in allocating the available funds for mitigation and any related new infrastructure investment to participating agencies could help reduce the current uncertainties in drought response. Such actions also would help to resolve challenges identified by some of the stakeholders interviewed as part of this study (such as the perception that drought mitigation interventions in the past were not as timely, effective, or beneficial as they could have been because of inadequate institutional coordination). Finally, there is a need to clearly recognize the link between the observed more frequent and severe droughts in Tunisia and global climate variability and change. This also reinforces the need for the country to better integrate its drought management and climate change adaptation policies and instruments.

ANNEX
2.1

CLIMATE CHANGE AND VARIABILITY IN MENA

This annex provides a brief update to information on climate, climate variability, and climate change presented in the World Bank's MENA region climate change flagship report,[50] emphasizing the peculiarities relevant to Tunisia and building on recent observational data and emerging scientific knowledge acquired since the Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5) was issued (IPCC 2013c). The focus in the sections that follow is on the physical climate system that is addressed by IPCC's Working Group I. This report considers progress in the understanding of the human and natural drivers of climate change, climate observations and attribution, and key climate feedback, in particular related to agricultural drought.

An update to the state of the global climate. The IPCC's AR5 (IPCC 2013c) concluded that:

> *"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased."*

Since then, several years' worth of observations have been added to the data, which are discussed later and considered in view of another significant climate phenomenon that has been dominant recently, El Niño.

Global mean temperature change. In AR5, it was established that the global average surface air temperature increased by approximately 0.85°C during the period from 1880 to 2012. In addition to robust multidecadal warming, global mean surface temperature exhibits substantial decadal and interannual variability (see Figure A2.1.1). As an example, the rate of warming from 1998 to 2012 was essentially consistent with no warming at all (the uncertainty range was assessed to be from –0.05°C to 0.15°C per decade), beginning with a strong El Niño.

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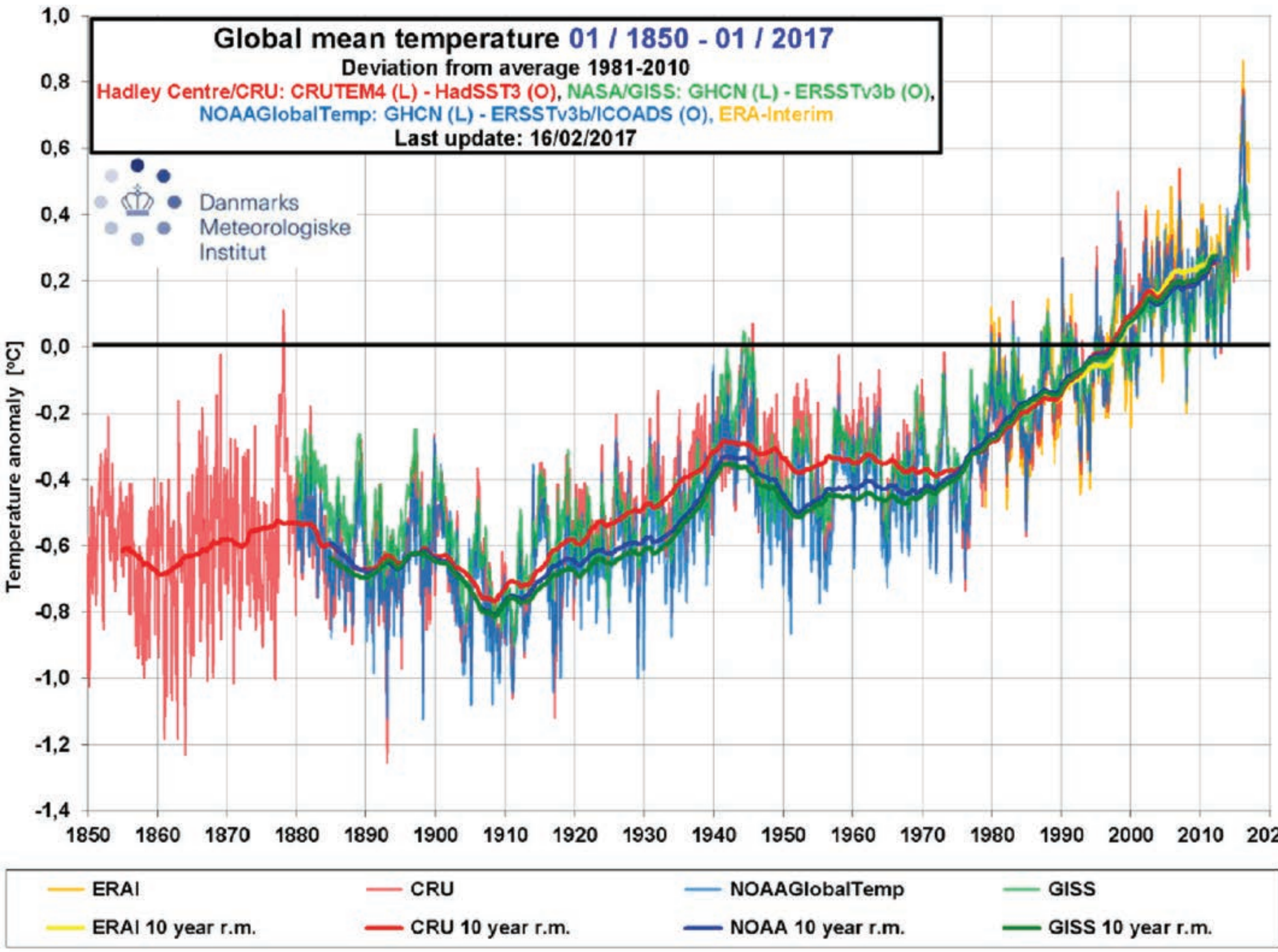
[50] See Chapter 2 by Christensen, J., Stendel, M., Yang, S. (Danish Meteorological Institute), Nobel, I. and Westphal, M. (World Bank). "Ways Forward for Climatology" in D. Verner (ed), Adaptation to a Changing Climate in the Arab Countries A Case for Adaptative Governance and Leadership in Building Climate Resilience, World Bank, Washington D.C., 2012, pp. 39-99.

FIGURE A2.1.1 Average Monthly Mean Global Temperature Anomalies, 1850–2017



Source: Danish Meteorological Institute (DMI).

Note: Annual mean temperature anomalies (*thin lines*) and 10-year running mean (*heavy line*) since 1850, according to the Climatic Research Unit (CRU) and Hadley Centre (United Kingdom Meteorological Organization) (*red*); since 1880 NASA/Goddard Institute for Space Studies (GISS) (*green*) and NOAA (*blue*), since 1979 European Center for Medium-Range Weather Forecasts (ECMWF) (*yellow*).

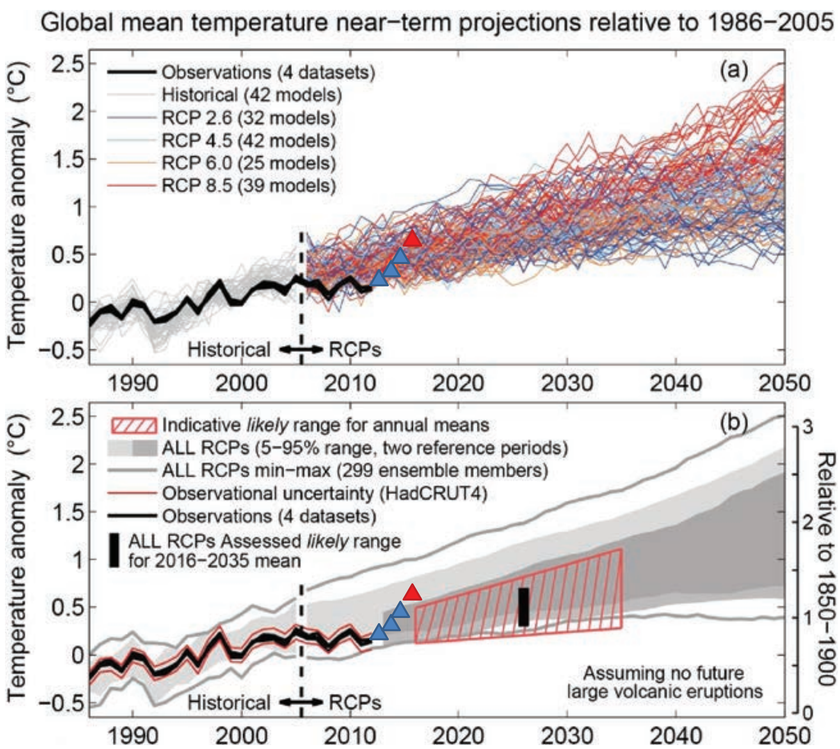
Since 2012, warming has picked up again, which is probably also a temporary development, but has resulted in a new and warmer baseline than pre-2012. The global mean temperature reached a new record high in 2016.[51] The magnitude of the global warming trend is expected to vary from year to year, despite being unambiguous over time. A decade is a short period when it comes to climate; the most recent decades are discussed later, both to provide an update on global temperature data and to elucidate the apparent reappearance of the continued warming trend.

[51] According to the United States National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), the global mean temperature in 2016 was 0.99°C (1.78°F) above the 20th century mean, making it the third year in a row to set a new record in global average temperatures. Not only was 2016 the warmest year on record, but 8 of the 12 months from January through September were the hottest (the only exception was June), and those from October through December were the second hottest on record. In addition, researchers estimate that the El Niño in effect from most of 2015 and the first third of 2016 increased the average temperature anomaly by 0.12°C (0.2°F).

The IPCC AR5's projections of 21st century temperature changes were based on simulations made by 42 global climate models (Flato et al. 2013), using the 20-year mean temperature for 1986–2005 as a baseline. For the 2006–12, period the observed global mean temperature rise has been lower than the average simulated by these models (Figure A2.1.2). However, the observed change was still well within the variation among the model results.

The global mean temperature is not expected to rise steadily from one year to the next because of natural climate variability. Part of the natural variability is caused by variations in solar activity and volcanic eruptions. For example, a temporary cooling was observed after the Mt. Pinatubo eruption in 1991, whereas low solar activity may also have affected the lack of warming (for example, Lockwood 2010). Apart from the scientific relevance of discussing what caused the warming pause (hiatus) between around 1998 and 2012, the fact that warming has picked up again is the main

FIGURE A2.1.2 Representation of Global Mean Surface Air Temperature by Climate Models, 1850–2050



Source: Stocker et al. 2013 with updates by authors.

Notes: RCPs refer to representative concentration pathways of greenhouse gas (GHG) emissions. (a) Projections of annual global mean surface air temperature (GMST) 1986–2050 (relative to 1986–2005) under all RCPs from CMIP5 models (*gray and colored lines*), with four observational estimates (Hadley Centre/Climatic Research Unit gridded surface temperature data set 4; HadCRUT4), European Centre for Medium-Range Weather Forecasts (ECMWF) interim reanalysis of the global atmosphere and surface conditions (ERA-Interim), Goddard Institute for Space Studies Surface Temperature Analysis (GISTEMP), National Oceanic and Atmospheric Administration (NOAA) for the period 1986–2012 (*black lines*). (b) As (a) but showing the 5 to 95 percent range of annual mean CMIP5 projections for all RCPs using a reference period of 1986–2005 (*light gray shade*) and all RCPs using a reference period of 2006–12, together with the observed anomaly for (2006–12) minus (1986–2005) of 0.16°C (*dark gray shade*). The maximum and minimum values from CMIP5 using all ensemble members and the 1986–2005 reference period are shown by the gray lines. Black lines show annual mean observational estimates. The red shaded region shows the indicative likely range for annual mean GMST during the 2016–35 period. The temperature scale relative to 1850–1900 mean climate on the right-hand side assumes a warming of GMST before 1986–2005 of 0.61°C estimated from HadCRUT4. Also shown by blue and red triangles are the observed annual mean temperatures for 2013–16 based on the same data providers. The size of the symbols represents a measure of uncertainty in estimating the annual mean temperature.

concern of this report. Figure A2.1.2 summarizes the discussions from AR5 about how the hiatus, if it is to be dominating in the years ahead, would influence the IPCC-assessed, near-term likely global warming. However, it should be noted that decadal variability should always be considered when trying to attribute global temperature trends, and as a result of the most recent continued warming trend, the discussion about the potential extension of the global warming hiatus has become obsolete.

Significant natural variability is generated by internal fluctuations within the climate system, particularly in the oceans. The year 1998, with its exceptionally strong El Niño warming in the tropical Pacific for a long period, stood out as the one with the highest global mean temperature in each of the observational analyses. In contrast, the relative coolness of 2008 coincided with a La Niña, which is the opposite of an El Niño (and is discussed later in this annex). The strong El Niño in 2015–16 clearly altered the importance of what happened in 1998. Thus, a key element to be kept in mind is that the hiatus commenced and was interrupted by two remarkably strong El Niño events.

El Niño as regional driver of variability. El Niño is a natural climatic phenomenon that occurs every second to seventh year in the tropical Pacific. Because of the scale of this phenomenon, it affects weather over much of the globe. In Spanish, El Niño means "boy child" or "baby Jesus." It got its name because a weak, relatively warm ocean current is found along the Peruvian and Ecuadorean coasts in most years at Christmas time. The phenomenon has been recognized for centuries among local fishermen. But only in recent decades has its scale become known. Today El Niño designates a period of unusual warming of water along the South American west coast and in the central parts of the Pacific Ocean. This affects marine currents and atmospheric circulation over most of the central Pacific Ocean. The total phenomenon, linking atmosphere and ocean processes, is called El Niño Southern oscillation (ENSO); the "Southern oscillation" refers to the atmospheric changes associated with El Niño.

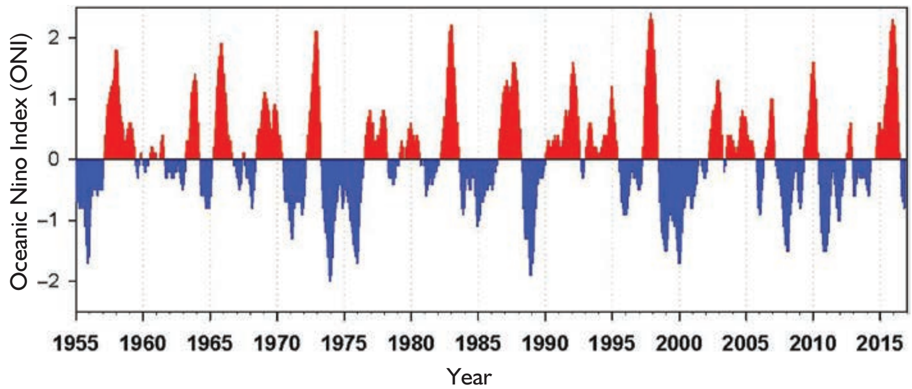
ENSO particularly affects the weather in countries bordering the tropical Pacific. Among other effects these include heavy rainfall along the west coast of South America, whereas the Philippines, Indonesia, and Australia experience drier periods during an El Niño. After an El Niño, the sea in the eastern Pacific cools again. Often, but not always, the water temperature drops more than what is climate normal. This is the reverse state of El Niño and is called La Niña, which means "the girl." To define an El Niño or La Niña state, the Oceanic Niño Index (ONI) has been developed. ONI is a temperature anomaly range for the central Pacific between 5° south to 5° north and 120° to 170° west. This area is also called the Niño 3.4 region.

An El Niño is defined by an ONI greater than 0.5°C, that is, a 3-month mean temperature that is at least 0.5°C above the 30-year mean. Similarly, a La Niña is defined by an ONI lower than –0.5°C. Values between plus-minus 0.5°C are termed neutral. A moderate El Niño has an ONI greater than 1°C and a powerful El Niño one greater than 1.5°C. The same applies to La Niña, only with negative values for ONI. Figure A2.1.3 illustrates the development in ONI since the 1950s.

ENSO is sometimes considered to influence climatic conditions more remotely than in the vicinity of the central Pacific. Droughts and flooding worldwide are often perceived as being linked with a particular phase of ENSO. This is particularly the case for the stronger such events. Formally, however, it is quite difficult to attribute any remote influence. In reality, a number of climate phenomena interfere with each other and, in a changing climate, the relations between these may vary at all times. Therefore, this is a long-standing research topic in the scientific climate community (for example, as formulated in the World Climate Research Program core project CLIVAR's (climate variability and predictability) mission to understand the dynamics, interaction, and predictability of the coupled ocean–atmosphere system).

This complexity notwithstanding, simple correlation measures depict the most important regional influences of ENSO. Based on a long-time series of observed variations correlated with the phases of

FIGURE A2.1.3 Values of the Oceanic Niño Index, 1955 to the Present



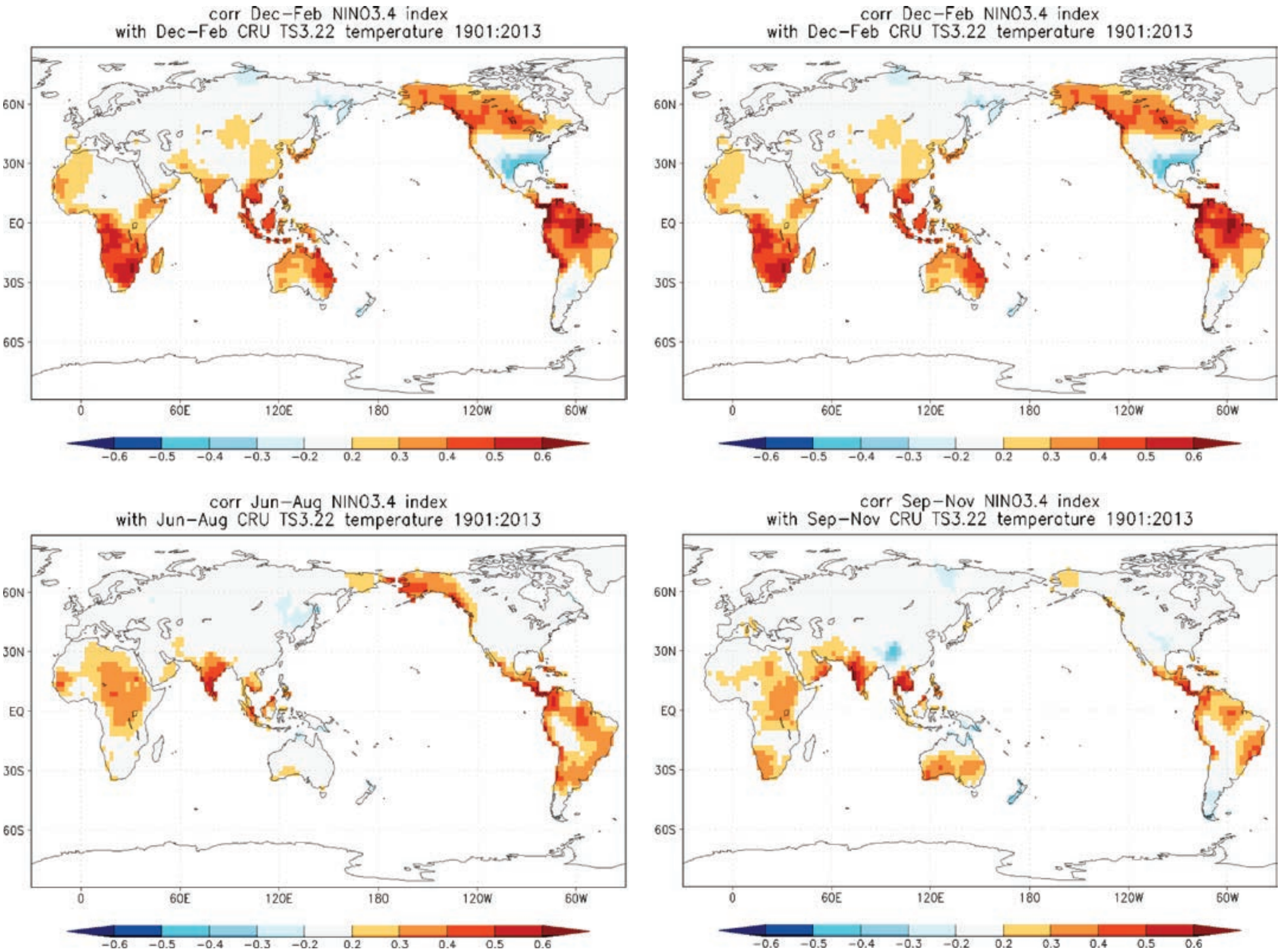
Source: NOAA (https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/cb-mei.cfm).
Note: Red bars indicate warm conditions in the equatorial Pacific; blue bars indicate cool conditions in equatorial waters. Large and prolonged El Niño events are indicated by large, positive values of the index: note the values greater than +2 are associated with the 1972, 1983, 1998, and recent strong event in 2015–16. Recent cool anomalies (La Niña) occurred 1999–2002, 2007–09 and 2010–12.

ENSO, it is possible to identify whether and where there is a remote ENSO influence (a teleconnection). Figures A2.1.4a–d and A2.1.5a–d do exactly this. Figure A2.1.4 displays the geographical correlation of temperature anomalies with the ONI described above. When the correlation is positive (shown in red), temperatures tend to be warmer than normal during an El Niño event and cooler during La Niña. Negative correlations (in blue) mean that the temperature signal is reversed.

From these maps, it is evident that the MENA region is only marginally influenced by ENSO in general. This is also confirmed by other studies (for example, Liu et al. 2014). Possible exceptions to this rule are a weak to moderate positive correlation between temperature and the phase of ENSO in northwest Africa from December to May and a weak positive correlation in northern Africa from June to August. For precipitation, there is a weak (possibly even moderate) anticorrelation with the phase of ENSO in northwest and North Africa from December to May and a weak positive correlation in North Africa and possibly in parts of the Middle East limited to the months of September to November. But in all cases, it is incorrect to solely attribute temperature or precipitation anomalies in these regions to the particular phase of ENSO. Only a weak signal appears to be identified at the specific country level (for example, for Morocco, Tunisia, and Lebanon). Instead, Christensen et al. (2013) concluded that the most dominant climate phenomena influencing the entire Mediterranean region is the phase of North Atlantic oscillation (NAO), particularly during the northern hemispheric winter. Christensen, Stendel, and Yang (2012) summarize this more specifically for the MENA region.

It is formally possible to assess the predictability of drought conditioned by teleconnection resulting from ENSO. Many research centers around the world are working on seasonal to decadal scale prediction systems. This involves large computational efforts with data assimilation elements from all parts of the climate system (atmosphere, ocean, cryosphere, land surfaces). These efforts have produced large databases with synthetic climate records for a time span representing many centuries and even millennia. Using models, it is possible to establish a statistically sound and thus robust basis for identifying correlations such as those depicted in Figures A2.1.4 and A2.1.5. In these maps, however, the correlations are not screened for robustness. For example, at each grid cell, the length and quality of the observational records are not depicted. In other words, it is not obvious if, at the grid point level, the correlation will

FIGURE A2.1.4 Temperature Correlation Maps



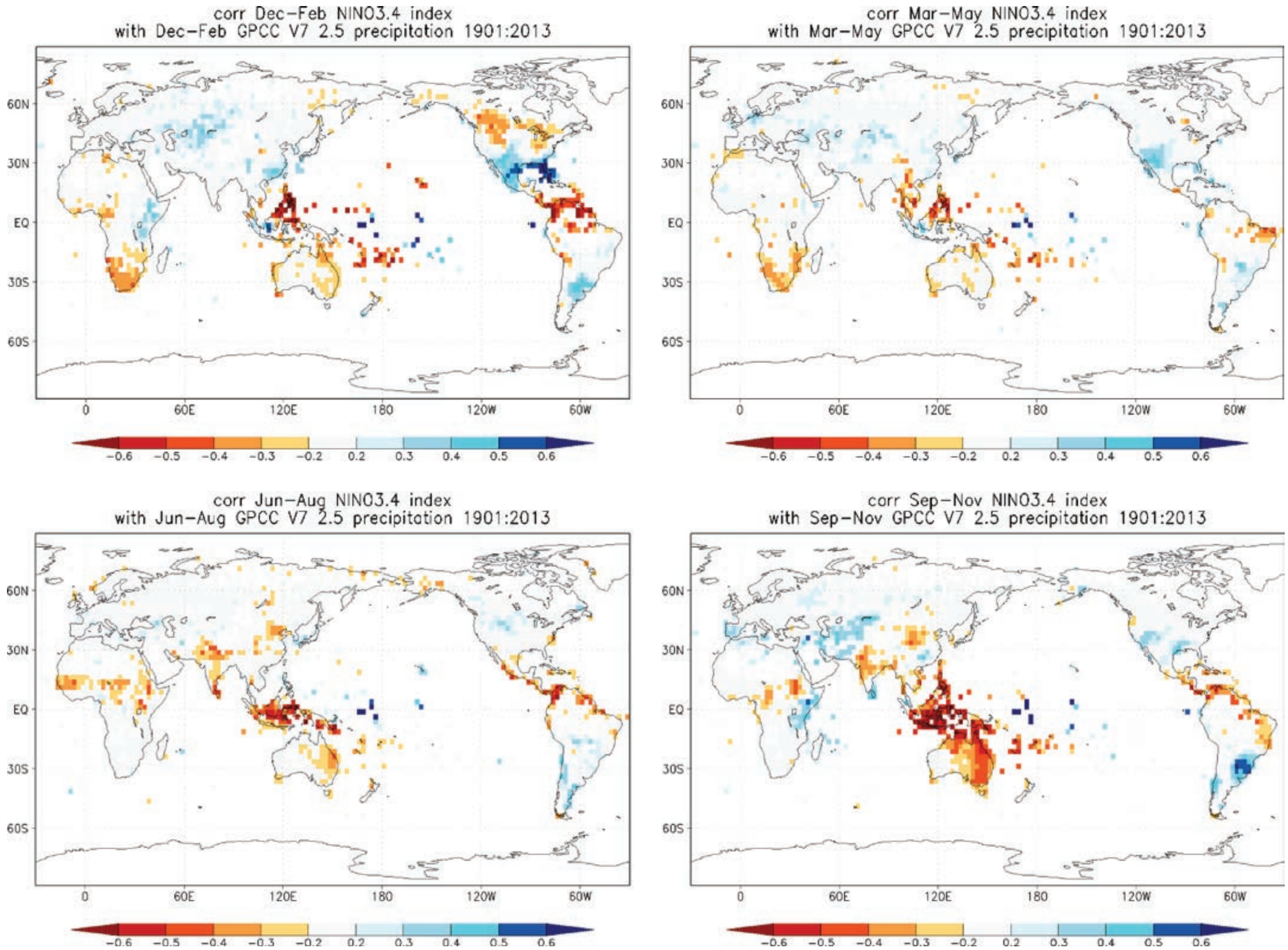
Source: KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi).

Notes: Red colors denote locations that on average are warmer during El Niño and cooler during La Niña. Blue colors are colder during El Niño and/or warmer during La Niña. Some North American effects are nonlinear: the effect of La Niña is not the opposite of the effect of El Niño.

remain the same if additional data from missing years are added. A second limitation is attributable to purely statistical reasons. For example, even if the correlation for dry/wet conditions under La Niña/El Niño is moderately high (for example, 0.5), the probability for the occurrence of the local dry/wet event is only 25 percent (0.5 times 0.5). Thus, 75 percent of the apparent structures may be entirely the result of chance and thus represent a false signal.

These formal limitations can be addressed using models. Here the modeled fields of temperature and precipitation can be analyzed against the modeled occurrence of ENSO. If statistically significant correlation is identified—typically correlation factors above 0.3 or below -0.3 are considered—potential predictive ability is identified. This is potential because it is realized only in a model and still has to be demonstrated for the real world to be valid. For small correlations, the real world attribution is even harder to obtain because of the lack of long-time series and thus observed events. Thus, potential predictive ability often is considered as important as real predictive ability.

FIGURE A2.1.5 Precipitation Correlation Maps



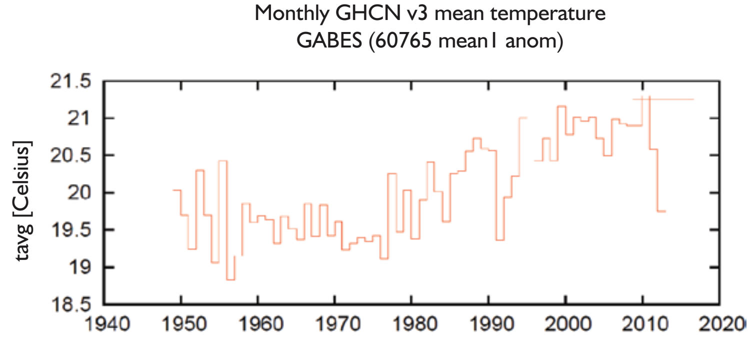
Source: KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi).

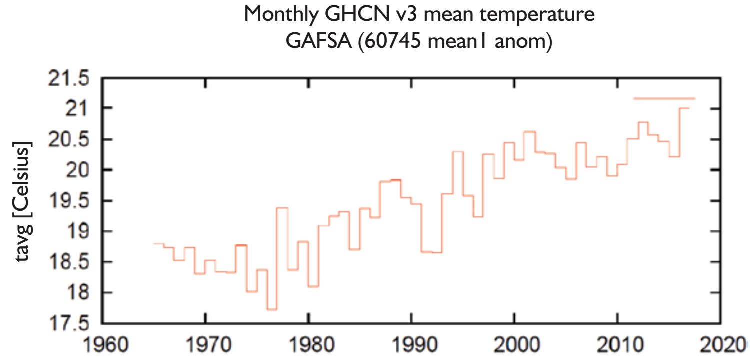
Notes: Blue colors indicate that during El Niño there was, on average, more rain than normal; red colors indicate drought during El Niño. La Niña has the opposite effect in almost all locations. As a measure of the strength of the relationship, the correlation coefficient with the Niño 3.4 index was used. The square of this number gives the fraction of the variance that is explained by this aspect of El Niño.

ANNEX
2.2

ANNUAL MEAN TEMPERATURE AND PRECIPITATION TRENDS FOR FOUR METEOROLOGICAL STATIONS IN TUNISIA

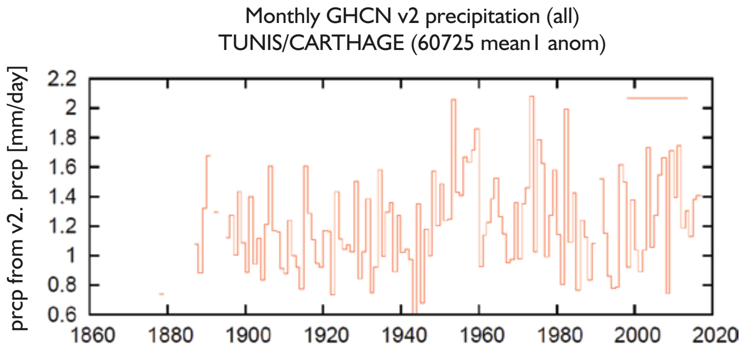
A2.2.1 TEMPERATURE

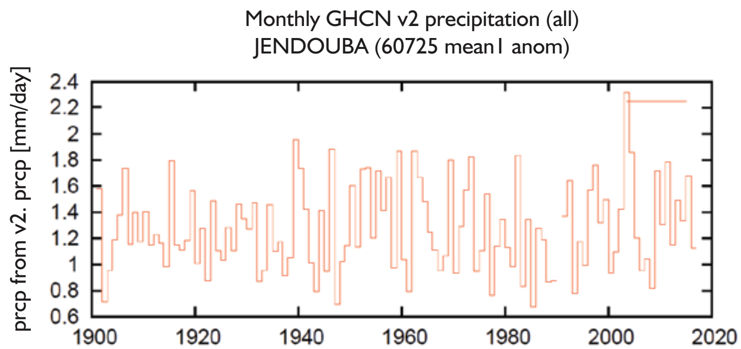


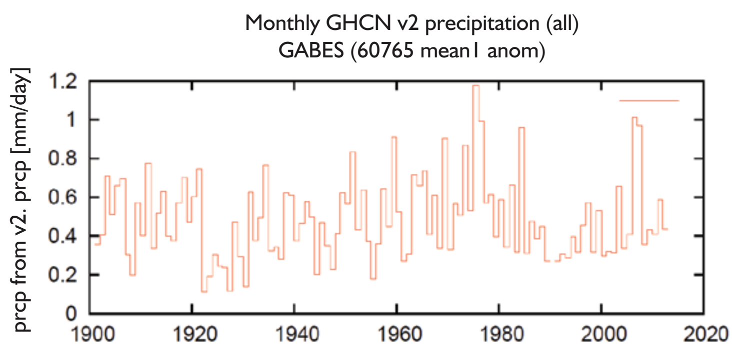


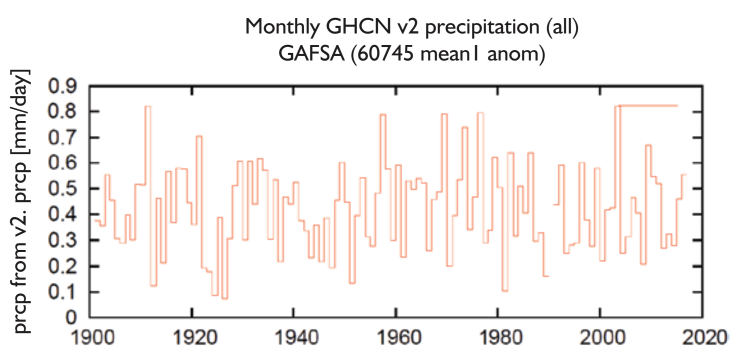
Source: KNMI Climate Explorer (https://climexp. knmi.nl/start.cgi).
Note: The series is nearly complete and terminates in 2016.

A2.2.2 PRECIPITATION









Source: KNMI Climate Explorer (https://climexp.knmi.nl/start.cgi).

ANNEX
2.3

CLIMATE-RELATED EVENTS IN TUNISIA AND NEIGHBORING COUNTRIES, 2007–15

- **2007** Tunisia and Algeria withstood a severe heat wave during June and July, during which the daily maximum temperature exceeded 47°C, breaking all-time high-temperature records in some locations.
- **2008** The year 2008 was characterized by several extreme weather events, including periods of heavy rainfall, heat waves, cold outbreaks, and strong winds. Several records were broken, and the annual mean temperature for northern Africa continued to rise. In northwest Africa, spring and summer 2008 were characterized by low rainfall totals, with March experiencing a deficit of more than 90%. However, autumn and winter 2007–08 were characterized by significant rainfall, especially across the northern regions. For October, many weather stations in the region, including Tunisia, reported 24-hour rainfall totals exceeding 200 mm. Several high daytime temperature records were set over the region in 2008. New records were set in particular in Morocco. A number of low nighttime records were also broken.
- **2009** Many weather stations in Morocco, Algeria, and Tunisia reported rainfall exceeding 150 mm in less than 24 hours. Heavy storms that occurred from December 20 to 25 produced heavy rains causing floods. Rainfall amounts as great as 200 mm in 48 hours were recorded in some locations. In Tunisia, more than 90 mm rainfall was recorded in less than four hours at Zarzis, Gribis, and Souihel during September. The year was characterized by these heavy rainfall events, causing important infrastructure damage and human life loss in many cities and villages. Record wind speeds also occurred; for example, 140 km hr^{-1} in Khouribga City in May and 115 km hr^{-1} in Tangier in December. Several forest fires occurred in July and August, especially when the daily temperature exceeded 50°C for some locations in Algeria and 49°C in Morocco. Tunisia was not so severely hit.
- **2010** The year 2010 was an exceptionally warm year in northern Africa. Annual temperature was 1.0°C to 3.0°C above normal in most regions (based on 1971–2000 base period). The warmth was influenced by extreme temperatures, which were reported mainly during the summer. Wet conditions were recorded during 2010 in North Africa; winter and autumn were characterized by episodes of intense rainfall and floods. Heavy rainfall exceeded the monthly average by more than 50 percent for most locations over the region. October and November were marked by significant heavy rainfall, leading to several floods. These events caused major

infrastructure damage and deaths. Many 24-hour rainfall records were broken during the year, particularly in Morocco. But near record events were seen in many places.

- **2011** Generally, both maximum and minimum temperatures were higher than average over the region. The year 2011 was the warmest in the last 10 years. The annual maximum temperature averaged between 0.5°C and 3.5°C above normal, with the largest anomaly observed in Taza, in the north-central sector of Morocco, south of the Rif Mountains. The annual maximum temperature anomaly was strongly influenced by extremely warm temperatures during the summer season. Overall, the annual precipitation was above average. During autumn, strong storms produced heavy rains and caused flooding in many locations in Algeria and Morocco, especially during October. October and November were marked by a succession of significant heavy rainfall events that led to several floods. These events caused important infrastructure damage and loss of human life, especially in Algeria. Also in Algeria, several forest fires associated with a heat wave and daily temperatures exceeding 49°C burned at the end of July and the beginning of August. An estimated 15,000 ha of land was affected, according to the Forestry Department of Algeria.
- **2012** Generally, 2012 was characterized by a succession of cold waves during the winter season accompanied by freezing temperature and snow. The summer months of July and August were warmer than normal with exceptional heat waves that settled in Algeria during the first 10-day period of July. Northern Africa tends to present a similar rainfall pattern with relative wet conditions during the Northern Hemisphere fall and winter and dry conditions in the spring and summer. Precipitation this year was marked by a strong regional disparity with rainfall deficits in the south and surpluses in the north. Overall, the annual precipitation was above average. Severe and unusually cold wave conditions prevailed over the region during the winter, particularly in January and February, claiming about 30 lives in Algeria. Several temperature records were established. The freezing temperatures were accompanied by record-breaking snow storms. In contrast, intense heat waves occurred during the summer season. The heat associated with predominant easterly winds favored the outbreak of several bush fires in Morocco and Algeria.
- **2013** In August, the daily maximum temperatures ranged from 41°C in coastal areas to 49°C in southern areas of the region. During summer, especially August, the presence and intensification of the Saharan heat low generated deep convective systems over the region. New seasonal record rainfall amounts were registered in Bousalem, Tunisia, where a total of 118 mm was recorded. Heavy rains associated with violent storms prevailed over the region during the spring and again in August, causing serious property damage and casualties, with seven fatalities in Algeria. Freezing temperatures associated with the heavy snowfall that occurred in February resulted in the loss of lives. Heat waves associated with continental easterly winds and temperatures near 50°C favored several forest fires.
- **2014** The annual temperature was above normal across the region. During the summer season, heat waves occurred over the region, notably during August. The highest absolute temperature of 50°C was reported in southern Algeria at Ouarglaon on August 2. Maximum daily temperatures generally ranged between 44°C and 46°C in Algeria and interior parts of the region in general. Overall, the region experienced an annual rainfall deficit, associated with anomalous anticyclonic circulation that persisted over the region, especially during the

first half of the year. However, the region also experienced a strong geographical variation in precipitation, ranging from 52% of normal at Nador, Morocco, to 239% of normal in El Jadida, Morocco. Snowfall of 2 to 3 cm was reported at Mount Assekrêm in Algeria on January 30. This is the first snowfall report over this Atlas Mountains region since 1945. A major heat wave associated with predominant easterly winds occurred during the summer over the region. As a result of the dry conditions, Tunisia and Algeria had several bush fires, with about 12 ha and 38 ha burned, respectively. Several stations in the region reported record 24-hour precipitation in November, including in Tunisia.

- **2015** During January and February, a series of cold spells affected the region, resulting in heavy snow. Three meters of snow fell over northeastern Morocco during February, the highest total for February in the past 30 years. Conversely, May, July, and August were marked by several heat waves, resulting in high maximum temperatures. These heat waves were associated with continental dry air intrusions from the intense heat source in the Sahara. The heat waves, associated with an easterly wind, caused several forest fires, which devastated hundreds of hectares of forest.

ANNEX
2.4

PROJECTED GLOBAL CHANGES IN TEMPERATURE, FROST DAYS, AND TROPICAL NIGHTS

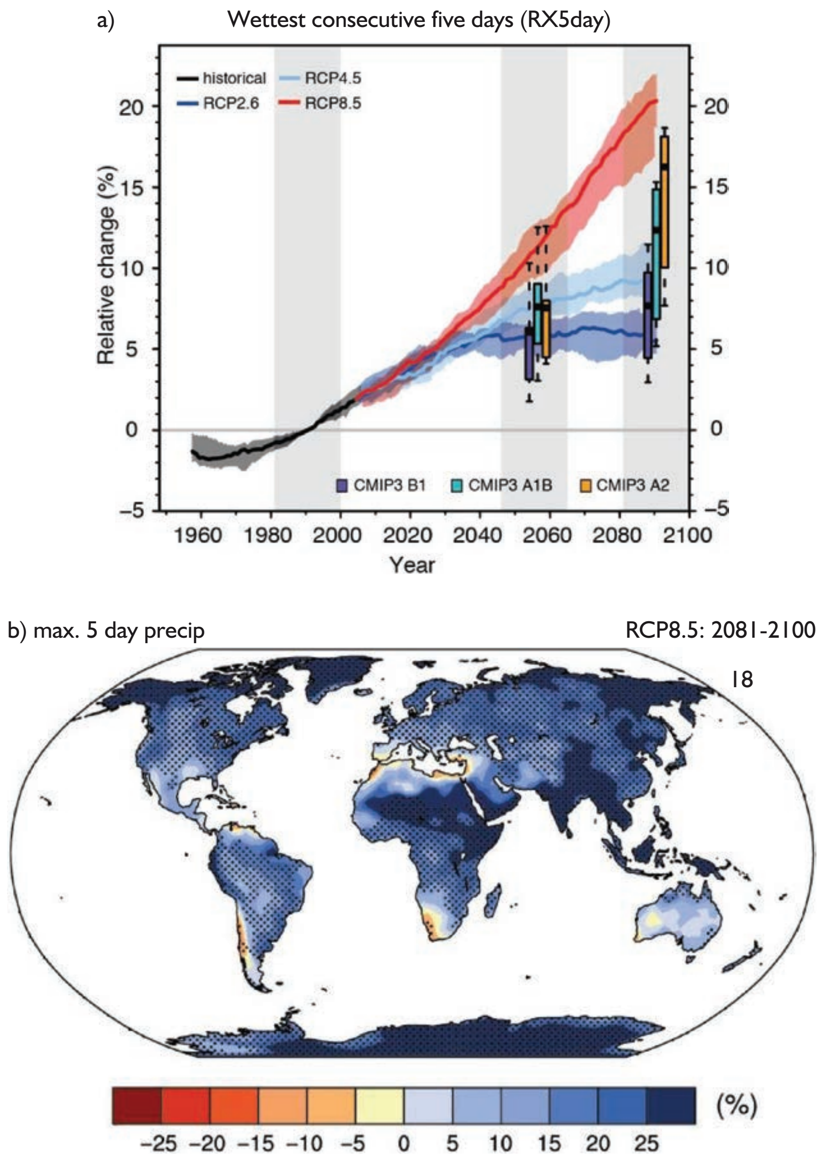
Figure A2.4.1 summarizes a multimodel analysis; this diagram shows simulated increases in five-day rainfall intensity between now and the end of the 21st century (upper panel). The lower panel shows a snapshot of the pattern of change toward the end of the century (2081–2100 versus 1986–2005). For northwest Africa and Tunisia in particular, the statistical signal is weak but with an indication of increasing risk of both increased rainfall intensity and from Figure 2.9 more frequent droughts or dry spells in general.

IPCC's AR5 assessed that "it is virtually certain that there will be more hot and fewer cold extremes as global temperature increases" (Collins et al. 2013). Figure A2.4.2 shows multimodel mean changes in the absolute temperature indices of the coldest day of the year and the hottest day of the year and the threshold-based indices of frost days and tropical nights from the CMIP5 ensemble.[52] A robust increase in warm temperature extremes and decrease in cold temperature extremes is found at the end of the 21st century, with the magnitude of the changes increasing with increased anthropogenic forcing. The coldest night of the year undergoes larger increases than the hottest day in the globally averaged time series (Figure A2.4.2b and d). This tendency is consistent with older (CMIP3) model results also shown, which use different models and the IPCC Special Report on Emission Scenarios (SRES). Similarly, increases in the frequency of warm nights are greater than increases in the frequency of warm days. Regionally, the largest increases in the coldest night of the year are projected under the RCP8.5 scenario (Figure A2.4.2a).

The subtropics and mid-latitudes exhibit the greatest projected changes in the hottest day of the year, whereas changes in tropical nights and the frequency of warm days and warm nights are largest in the tropics. The number of frost days declines in all regions, whereas significant increases in tropical nights are seen across the Mediterranean region and thus appear to be applicable to conditions of Tunisia. Using information regarding global figures, Collins et al. (2012) state that it is also likely that heat waves, defined as spells of days with temperature above a threshold determined from historical climatology, will occur with a higher frequency and duration, mainly as a direct consequence of

[52] In this figure, white areas over land indicate regions where the index is not valid. Shading in the time series represents the interquartile ensemble spread (25th and 75th quantiles). The box-and-whisker plots show the interquartile ensemble spread (box) and outliers (whiskers) for 11 Coupled Model Intercomparison Project 3 (CMIP3) simulations of the IPCC Special Report on Emission Scenarios SRES A2 (orange), A1B (cyan), and B1 (purple) globally averaged over the respective time periods (2046-65 and 2081-2100) as anomalies from 1981–2000 reference period.

FIGURE A2.4.1 Projected Percent Changes from the CMIP5 Models in Five-day Extreme Rainfall, the Annual Maximum Five-day Precipitation Accumulation



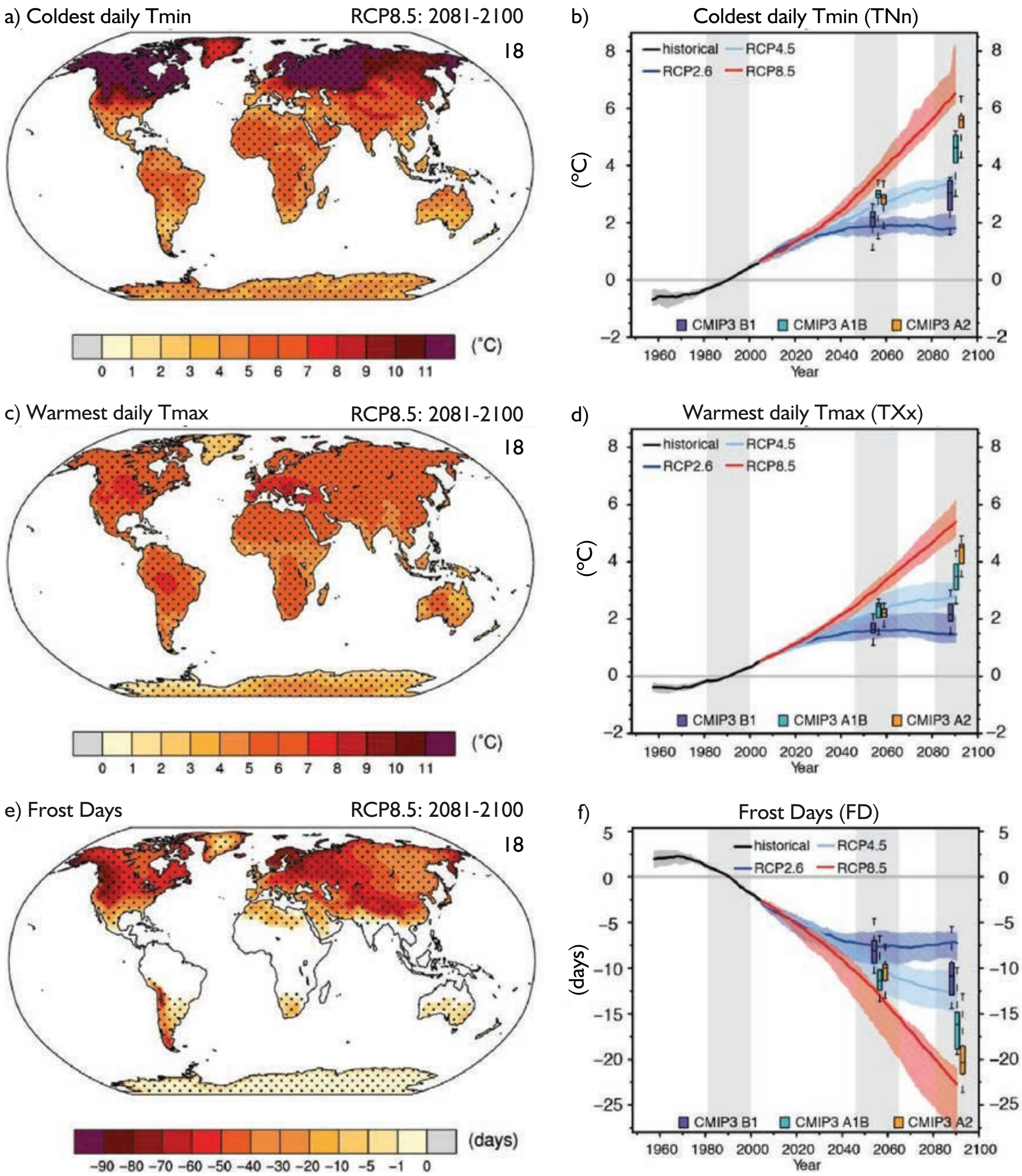
Source: Collins et al. 2013.

Notes: This is relative to 1981–2000 in common with CMIP3. (a) Global average percent change over land regions for the RCP2.6, RCP4.5 and RCP8.5 scenarios. (b) Percent change over the 2081–2100 period in the RCP8.5 scenario.[53]

the increase in seasonal mean temperatures. Changes in the absolute value of temperature extremes are also likely and expected to regionally exceed global temperature increases by far, with substantial changes in hot extremes projected even for moderate (for example, <2.5°C above present day) average warming levels.

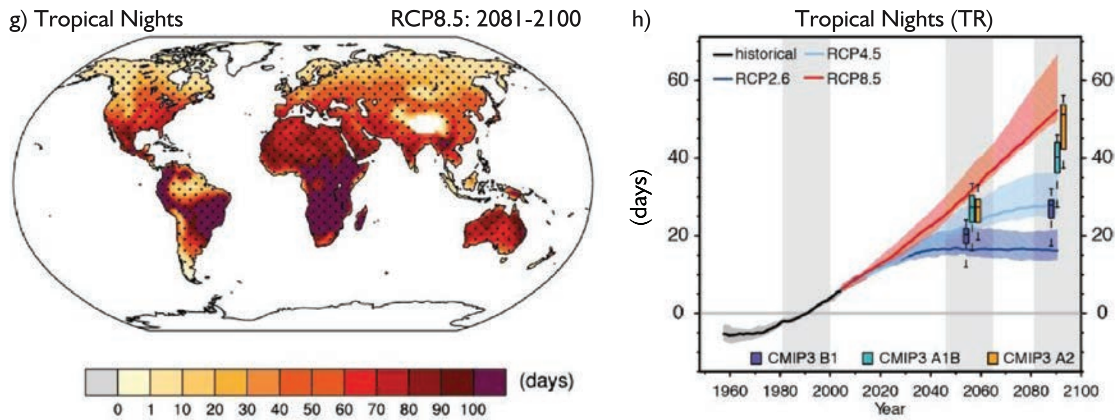
[53] Shading in the time series represents the interquartile ensemble spread (25th and 75th quantiles). The box-and-whisker plots show the interquartile ensemble spread (box) and outliers (whiskers) for 11 CMIP3 model simulations of the SRES scenarios A2 (orange), A1B (cyan) and B1 (purple) globally averaged over the respective future time periods (2046–65 and 2081–2100) as anomalies from the 1981–2000 reference period.

FIGURE A2.4.2 CMIP5 Multimodel Mean Geographical Changes under RCP8.5 and 20-year Smoothed Time Series for RCP2.6, RCP4.5, and RCP8.5



(*continues on next page*)

FIGURE A2.4.2 *(Continued)*



Source: Collins et al., 2013.

Notes: This is relative to 1981–2000 reference period in common with CMIP3. (a, b) Annual minimum of daily minimum temperature. (c, d) Annual maximum of daily maximum temperature. (e, f) Frost days (number of days below 0°C). (g, h) Tropical nights (number of days above 20°C).

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